SPECS

Seasonal-to-decadal climate Prediction for the improvement of European Climate Services

The Pinatubo eruption simulated under extreme phases of the Atlantic Multidecadal Oscillation

Martin Ménégoz, Christophe Cassou, Didier Swingedouw, Francisco Doblas-Reyes

MORDICUS Meeting,
Paris, November 2015

Introduction

→ Major eruptions bring Tg of particles into the stratosphere.

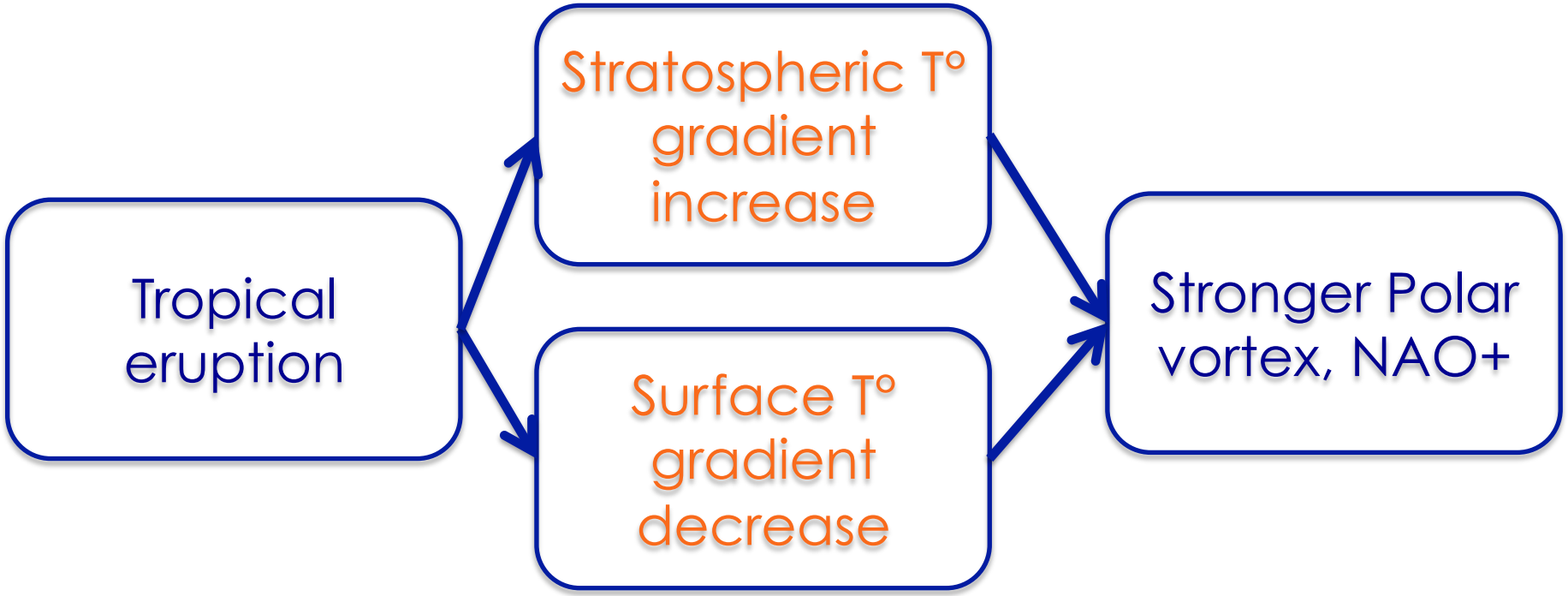
→ Strong radiative forcing => Global temperature decrease.

→ Direct atmospheric impacts during 5 years (NAO+?).

→ Potential retroactions involving changes of the ocean heat content during 10-20 years.

Sarychev volcano, 2009, NASA

Introduction



Robock (2000), Stenchikov, 2002

Introduction

NAO changes after volcanoes in the literature

→ Ortega et al. (2015): "Considering proxy data, a positive NAO emerges two years after strong volcanic eruptions".

→ Robock (2000), Stenchikov et al, 2002: "We model a NAO+ intensification the 1st and the 2nd winters after large tropical eruptions".

→ Driscoll et al. (2012): "CMIP5 models fail to reproduce the NAO+ intensification observed the two winters following major eruptions".

→ Toohey et al., 2014: "We do not model any significant change of the polar vortex the 1st winter following a Pinatubo-like eruption in simulations forced by observed forcing. The dynamical response to such eruption is strongly dependent on the space-time structure of the forcing".

Introduction

NAO change after volcanoes in the literature

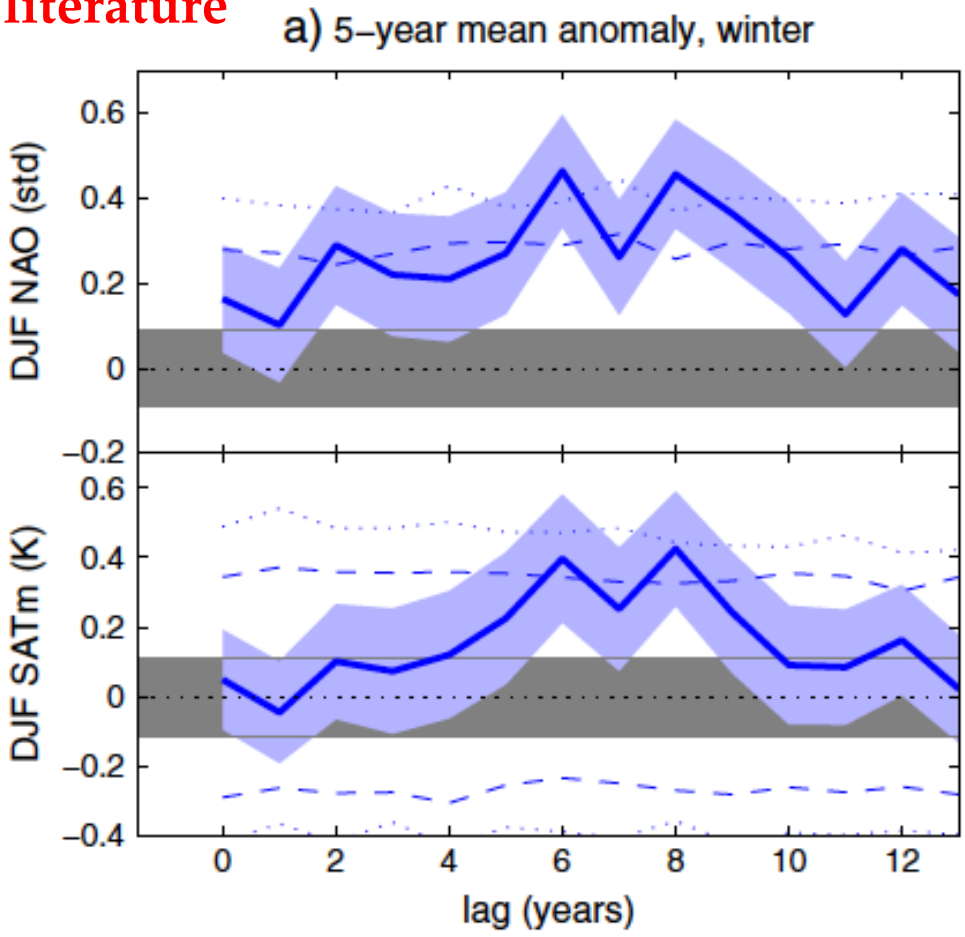
→ Zanchettin et al. (2013a): Oceanic and atmospheric responses to volcanic eruptions depend on the climate background conditions.

Introduction

NAO change after volcanoes in the literature

→ Zanchettin et al. (2013a): Oceanic and atmospheric responses to volcanic eruptions depend on the climate background conditions.

→ Zanchettin et al. (2013b): over the last 500 years, the NAO+ signal following tropical volcanic eruptions, shows a peak approximately one decade after the eruptions!

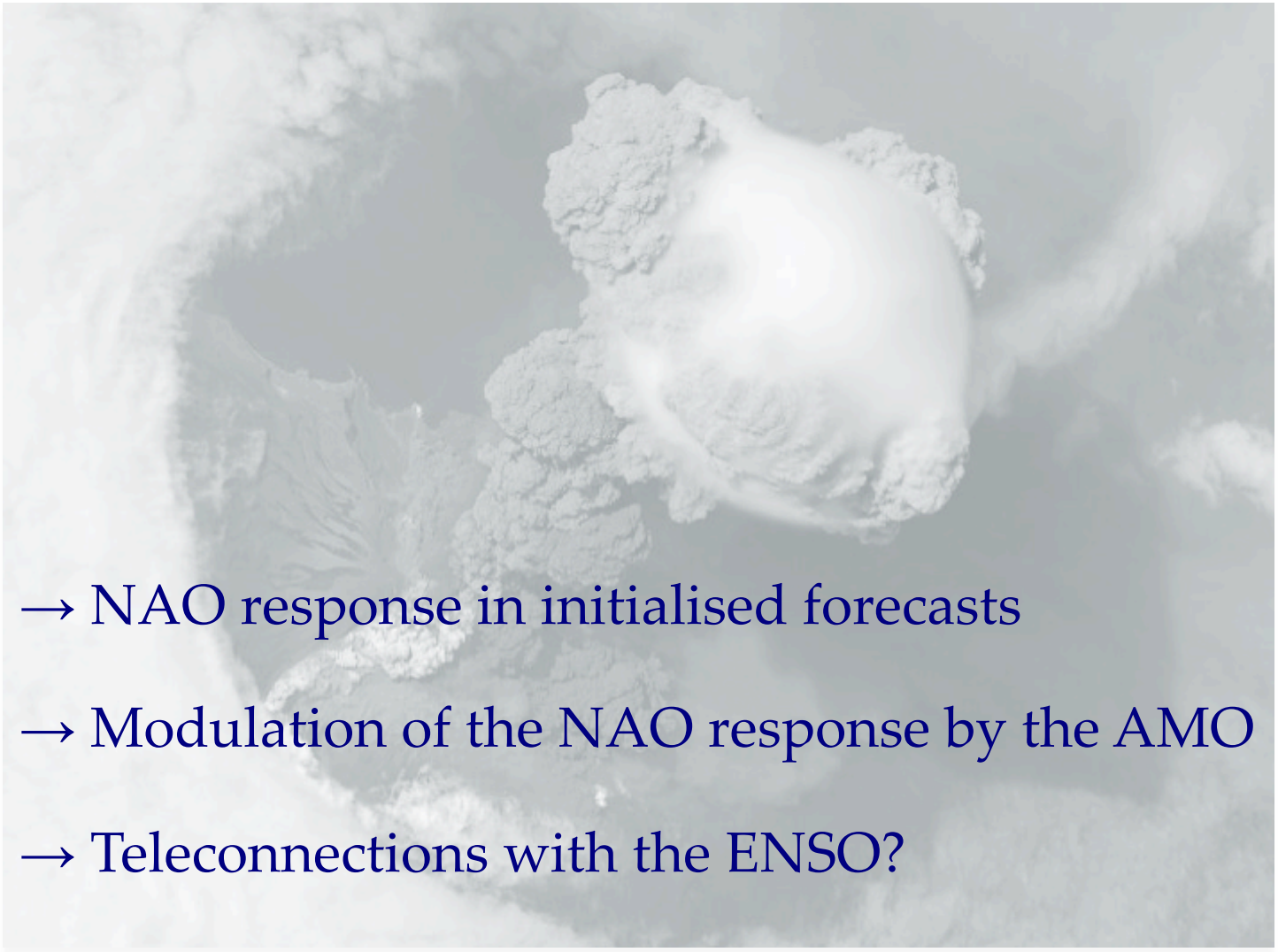


Zanchettin et al. (2013b)

Introduction

Do we catch a NAO+ signal after eruptions with EC-Earth and CNRM-CM5?

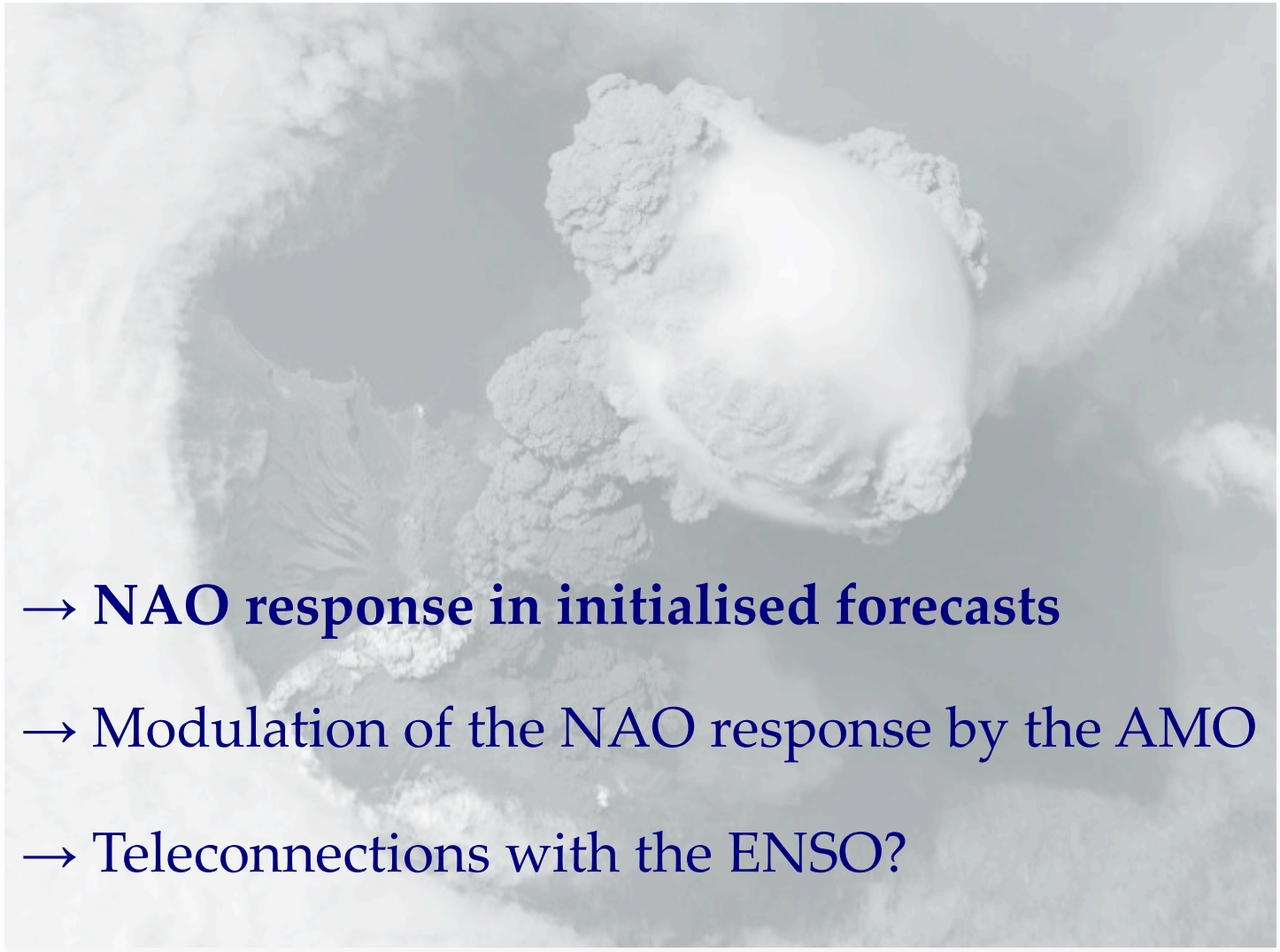
Does the Atlantic Multidecadal Oscillation (AMO) modulate this response?



→ NAO response in initialised forecasts

→ Modulation of the NAO response by the AMO

→ Teleconnections with the ENSO?



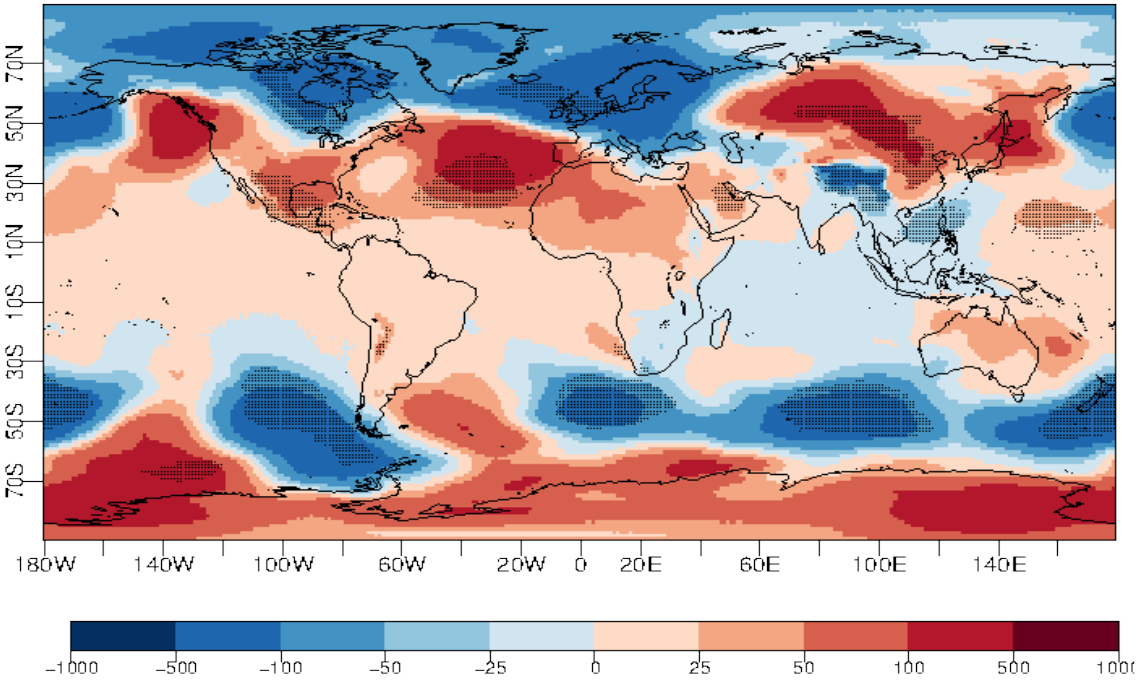
→ **NAO response in initialised forecasts**

→ Modulation of the NAO response by the AMO

→ Teleconnections with the ENSO?

Initialised forecasts

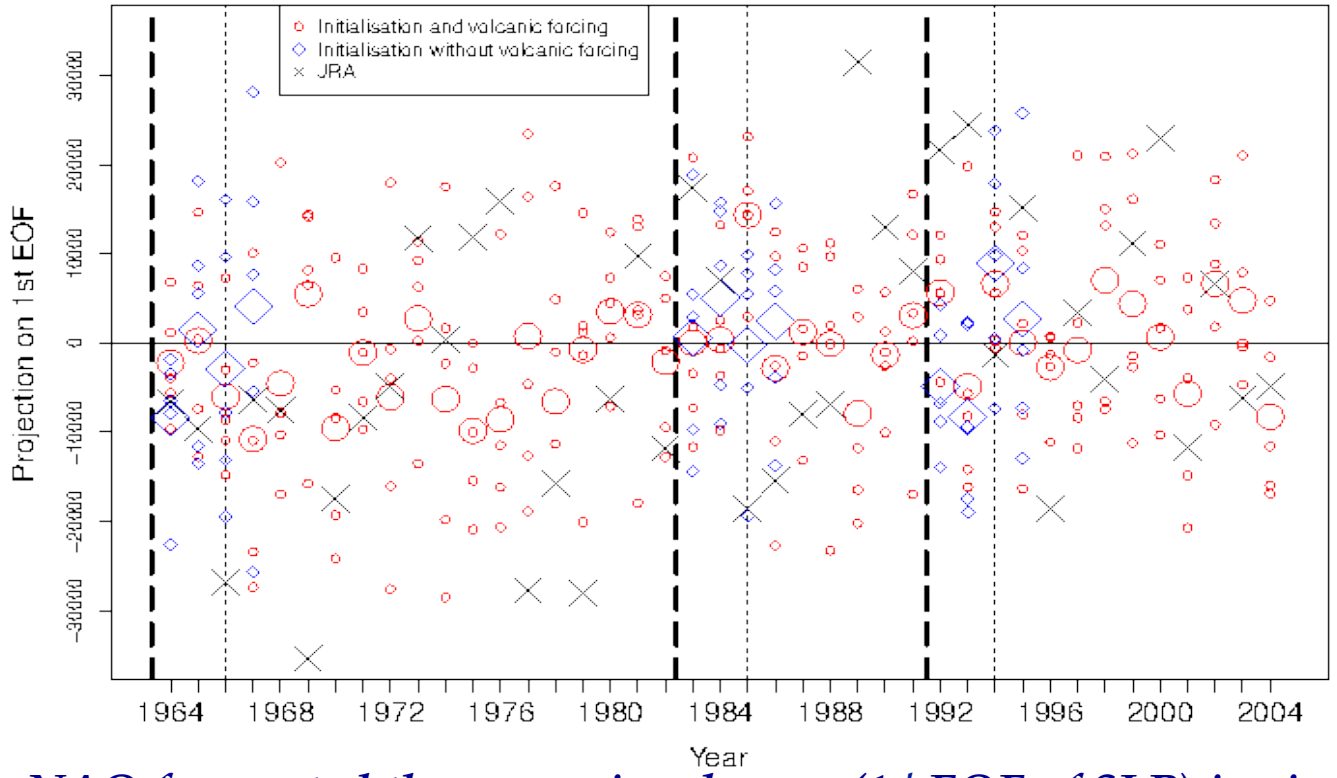
→ DJF forecasts: NAO+ signal the third winter after eruptions



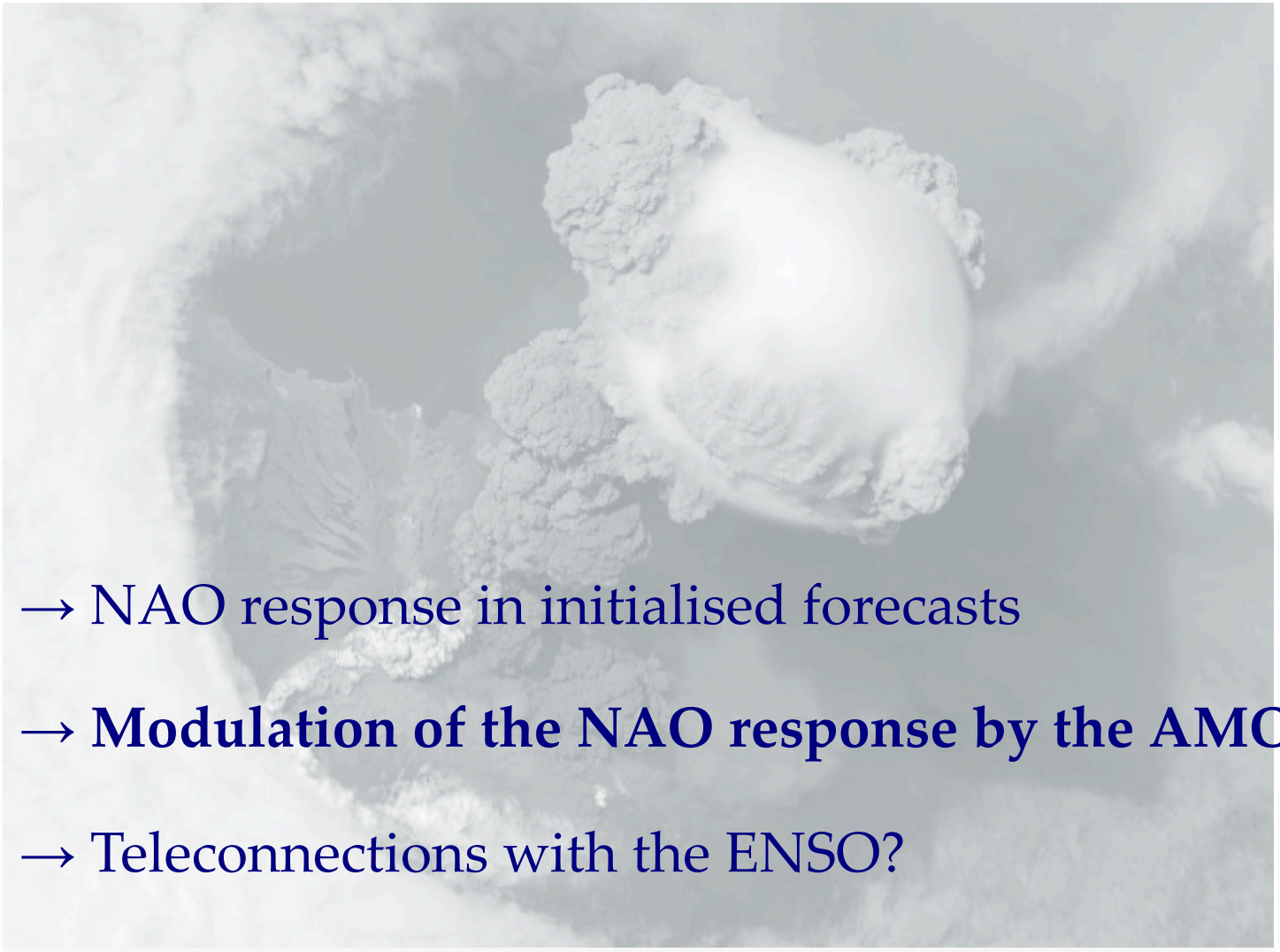
DJF SLP difference between simulations including and excluding volcanic forcing, the third winter on average after the three last major eruptions (Agung, El Chichon, Pinatubo). Simulations are initialised the year of the eruption.

Initialised forecasts

→ DJF forecasts: NAO+ signal the third winter after eruptions



Winter NAO forecasted three year in advance (1st EOF of SLP) in simulations initialised each year from 1961 to 2001, including (red) and excluding (blue) the volcanic forcing. Bold lines indicate the timing of the eruptions, light lines the third winter following the eruptions. Black crosses show the JRA NAO index.



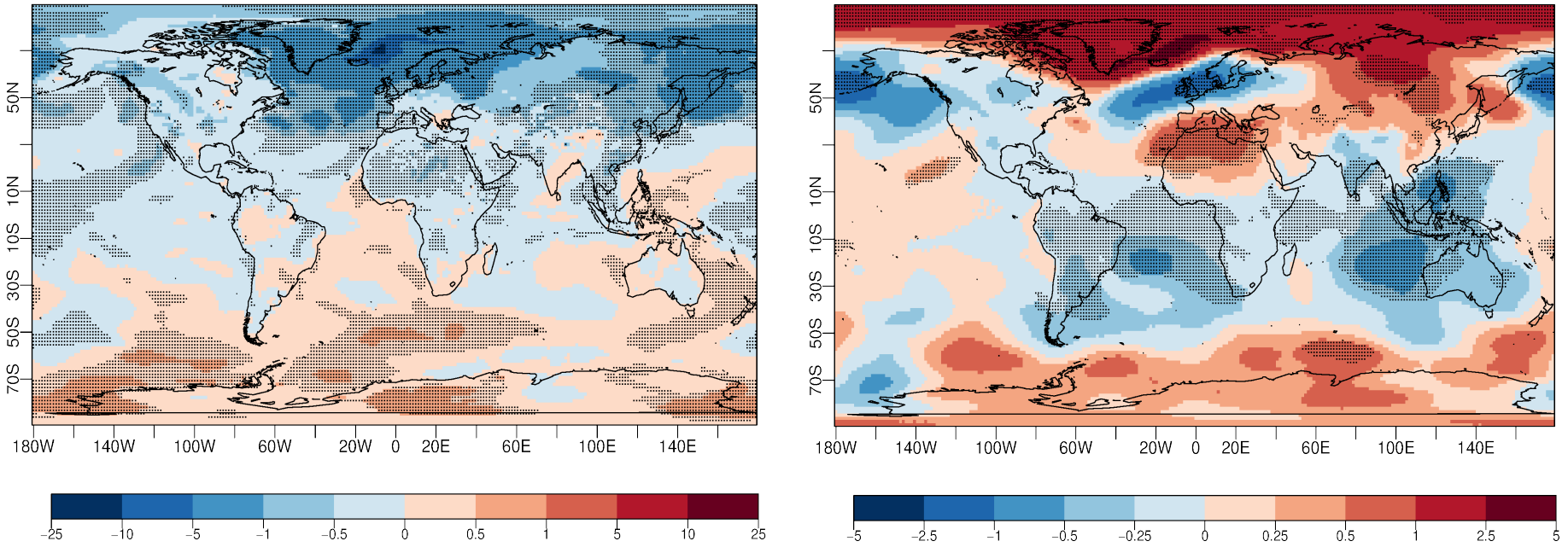
→ NAO response in initialised forecasts

→ **Modulation of the NAO response by the AMO**

→ Teleconnections with the ENSO?

Volcanoes, NAO and the AMO

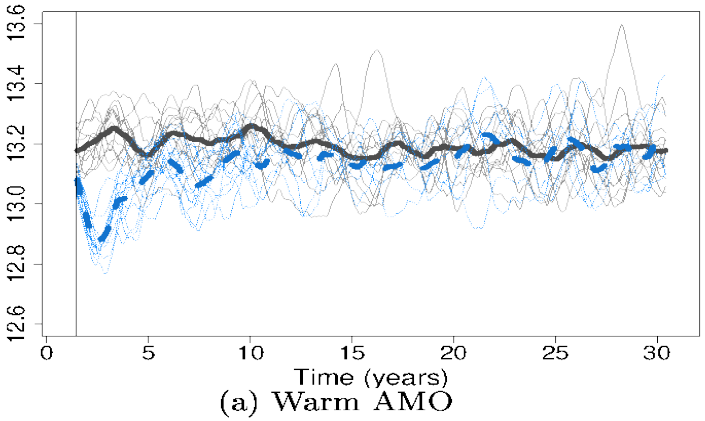
→ Extreme phases of the AMO in CNRM-CM5



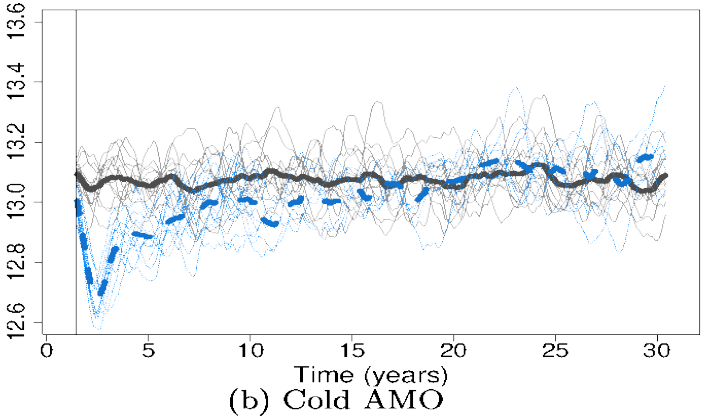
Winter surface temperature (left) and SLP (right) differences between extreme phases of the AMO in a CNRM-CM5 control simulation (cold AMO minus warm AMO).

Volcanoes, NAO and the AMO

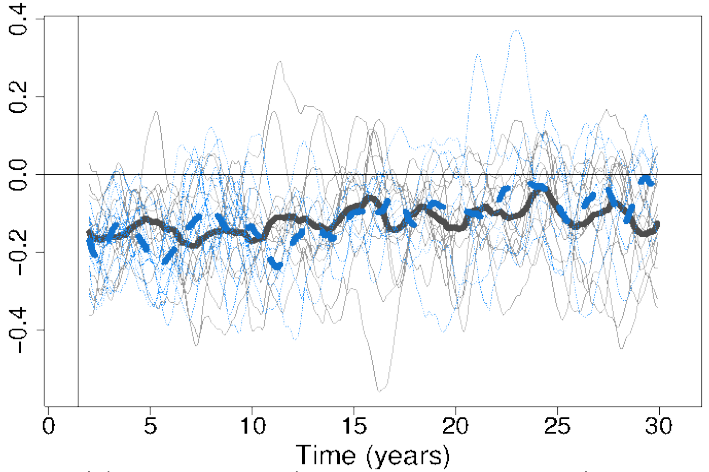
→ Global temperature response to volcanoes



(a) Warm AMO



(b) Cold AMO

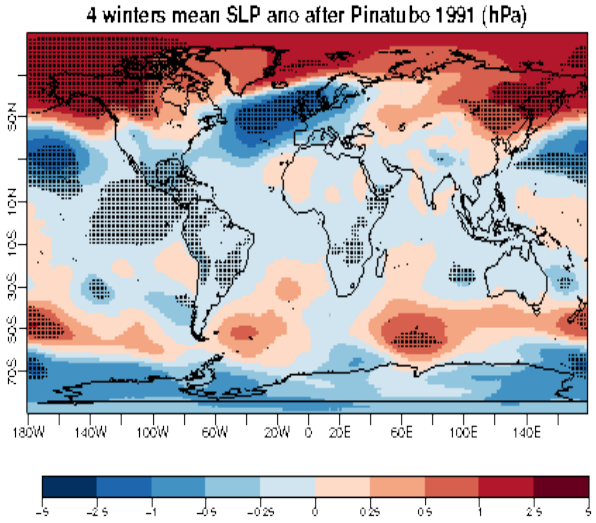


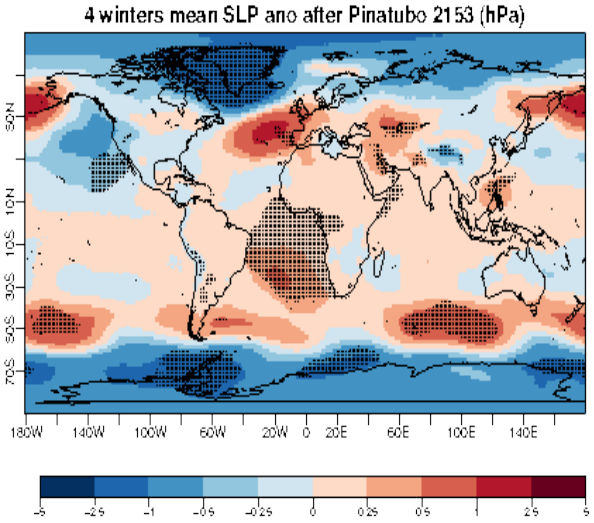
(c) Difference (Cold - Warm AMO)

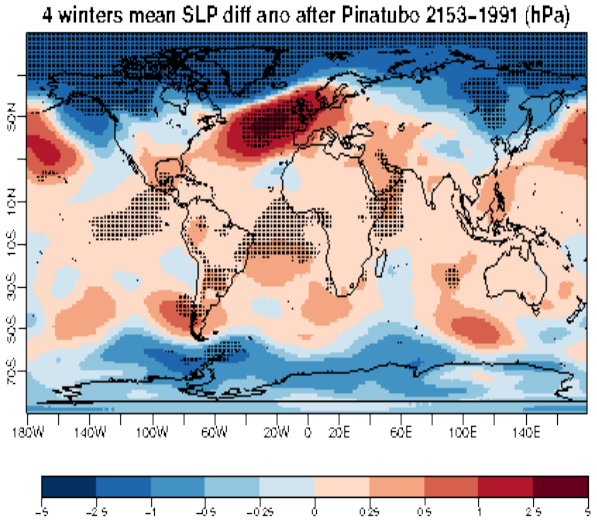
Global temperature (experiments with Pinatubo forcing in blue, CTRL exp in black). Vertical bar shows the year of the eruption

Volcanoes, NAO and the AMO

→ NAO+ signal after eruptions occurring under a cold AMO phase only



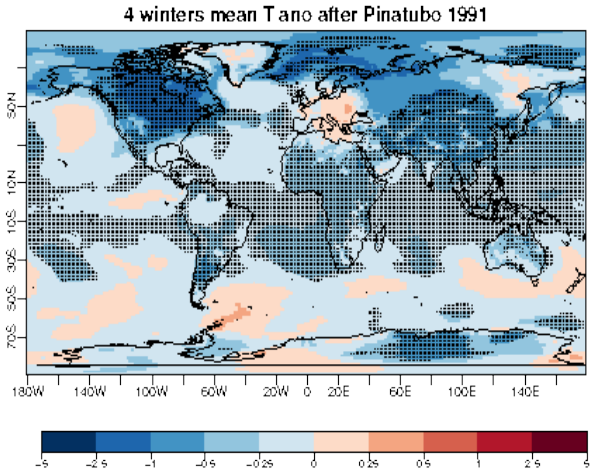




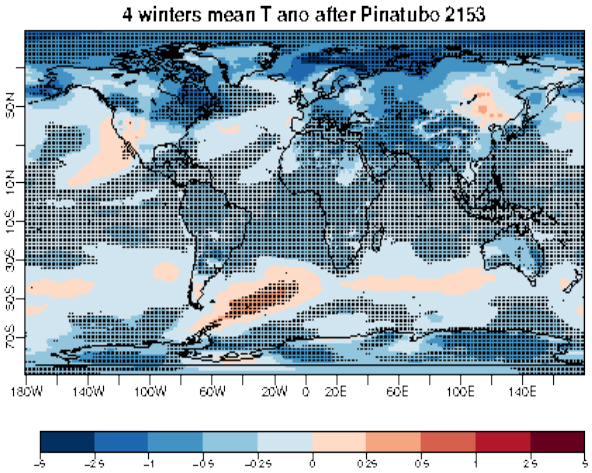
Winter SLP response to a Pinatubo-like eruption under extreme phases of the AMO in a CNRM-CM5 control simulation.

Volcanoes, NAO and the AMO

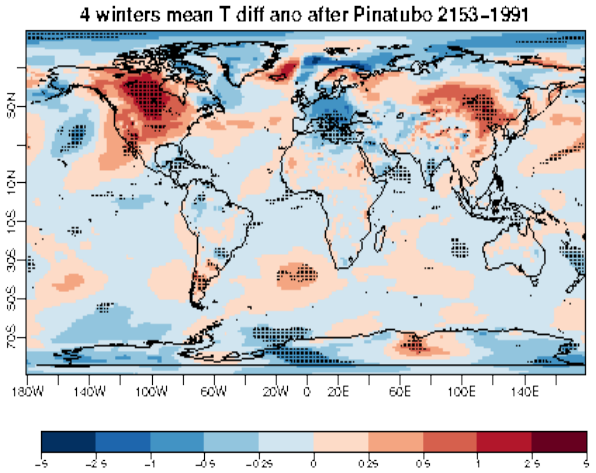
→ Surface temperature response



warm AMO



cold AMO

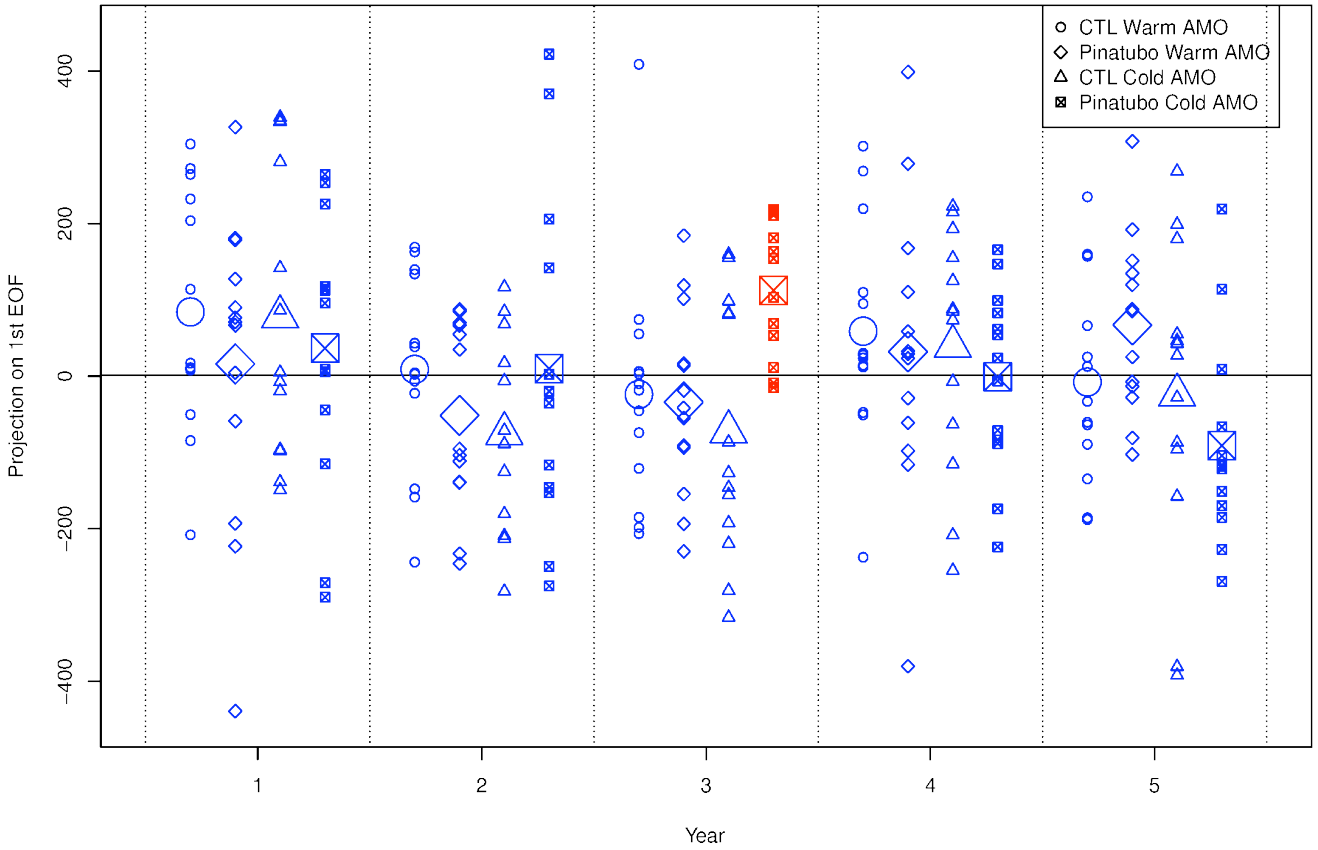


difference (cold - warm)

Winter surface temperature response to a Pinatubo-like eruption under extreme phases of the AMO in a CNRM-CM5 control simulation.

Volcanoes, NAO and the AMO

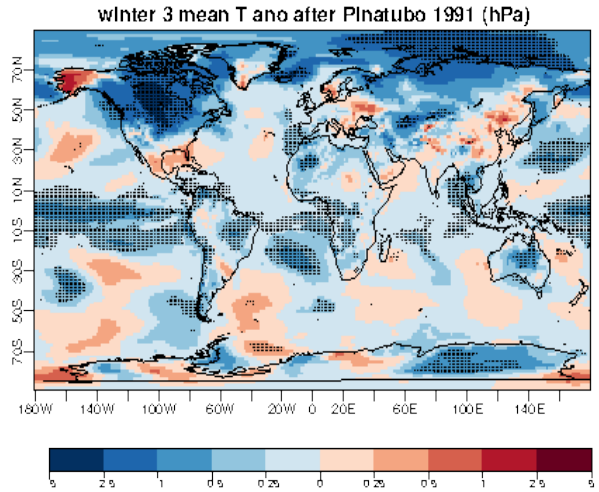
→ Significant NAO+ signal the 3rd winter after the eruption under a cold AMO



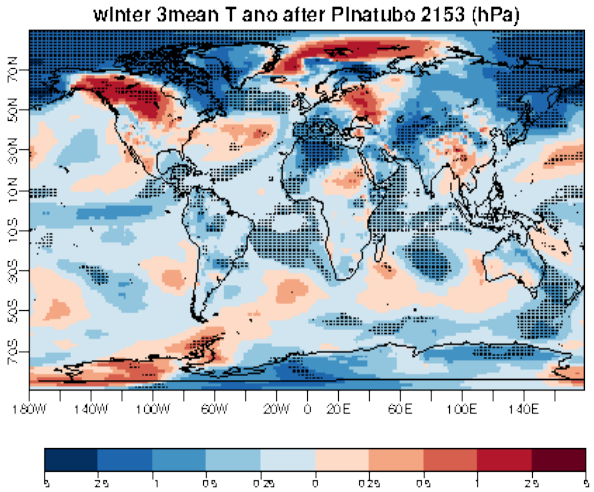
NAO index defined as projection on the first EOF of the SLP.
Simulation significantly different from the others appear in red.

Volcanoes, NAO and the AMO

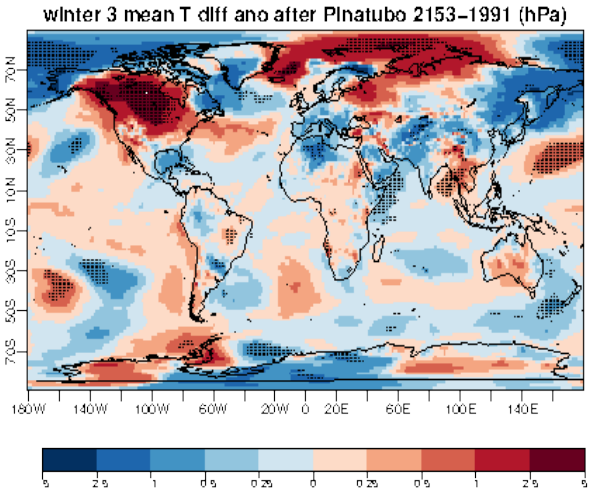
→ What's happen the third winter?



warm AMO



cold AMO

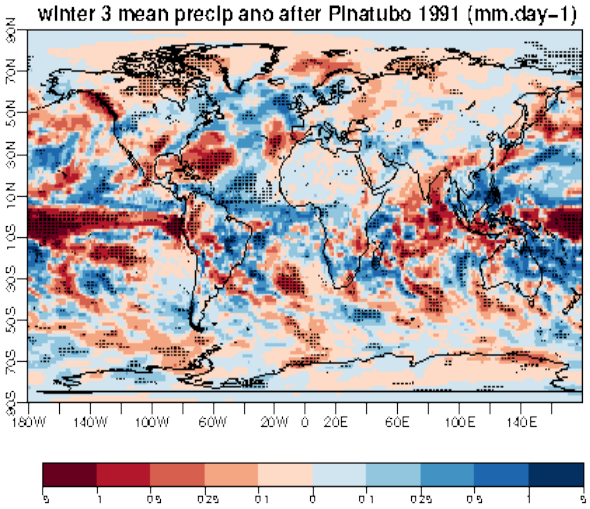


difference (cold - warm)

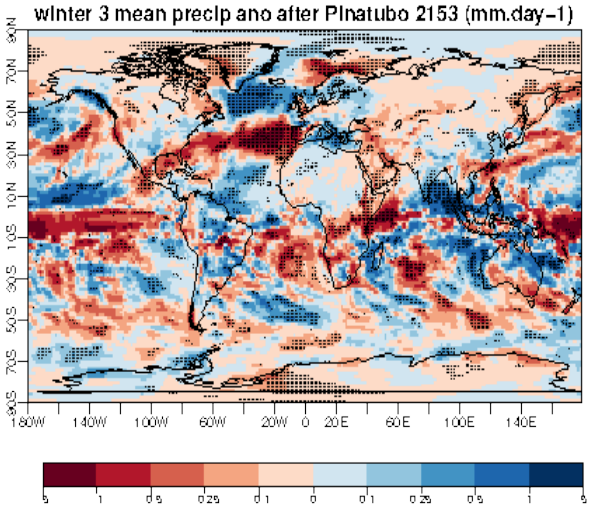
3rd winter surface temperature response to a Pinatubo-like eruption under extreme phases of the AMO in a CNRM-CM5 control simulation.

Volcanoes, NAO and the AMO

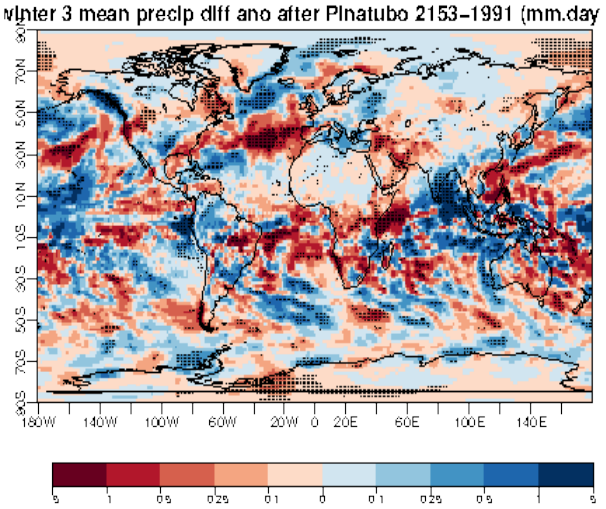
→ What's happen the third winter?



warm AMO



cold AMO

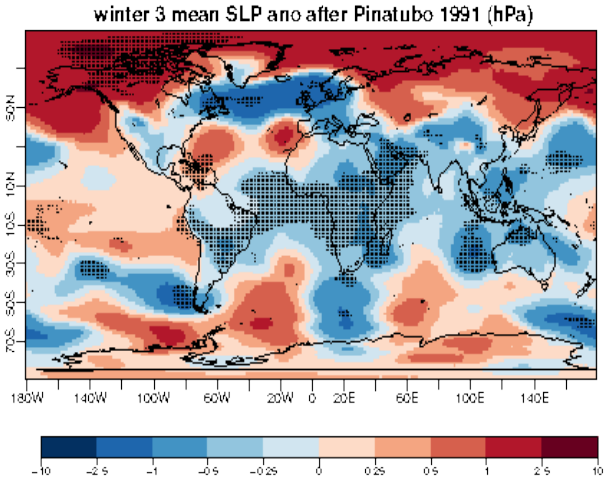


difference (cold - warm)

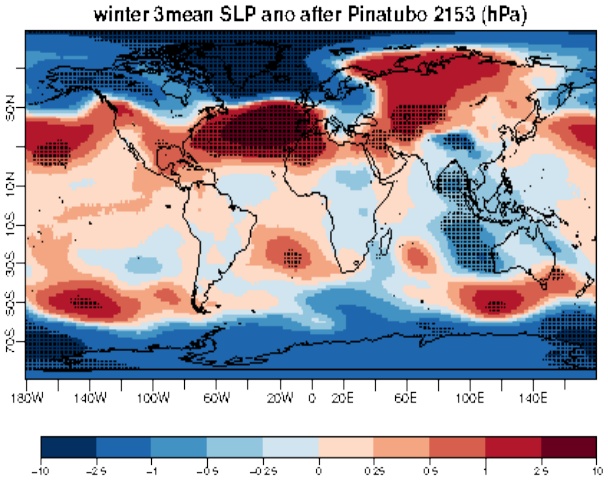
3rd winter precipitation response to a Pinatubo-like eruption under extreme phases of the AMO in a CNRM-CM5 control simulation.

Volcanoes, NAO and the AMO

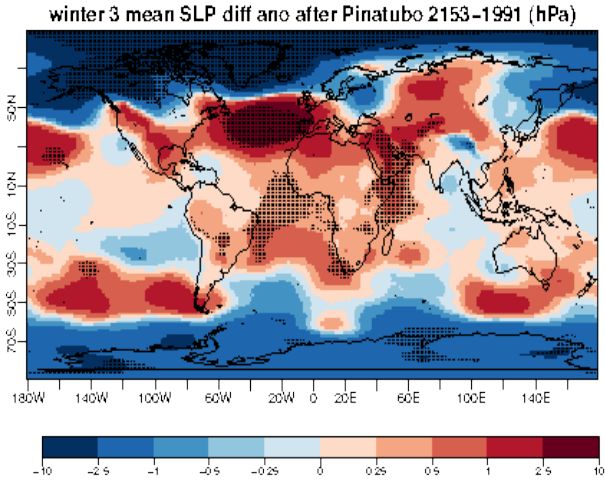
→ What's happen the third winter?



warm AMO



cold AMO

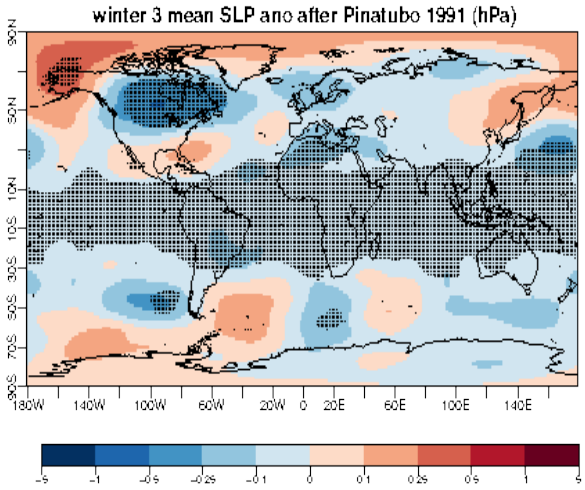


difference cold - warm AMO

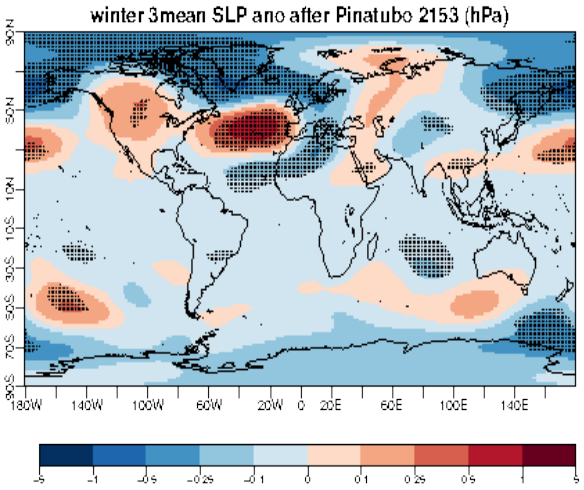
3rd winter SLP response to a Pinatubo-like eruption under extreme phases of the AMO in a CNRM-CM5 control simulation.

Volcanoes, NAO and the AMO

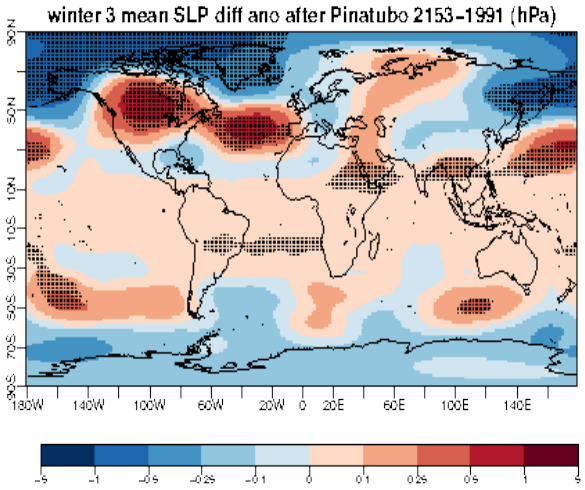
→ What's happen the third winter?



warm AMO

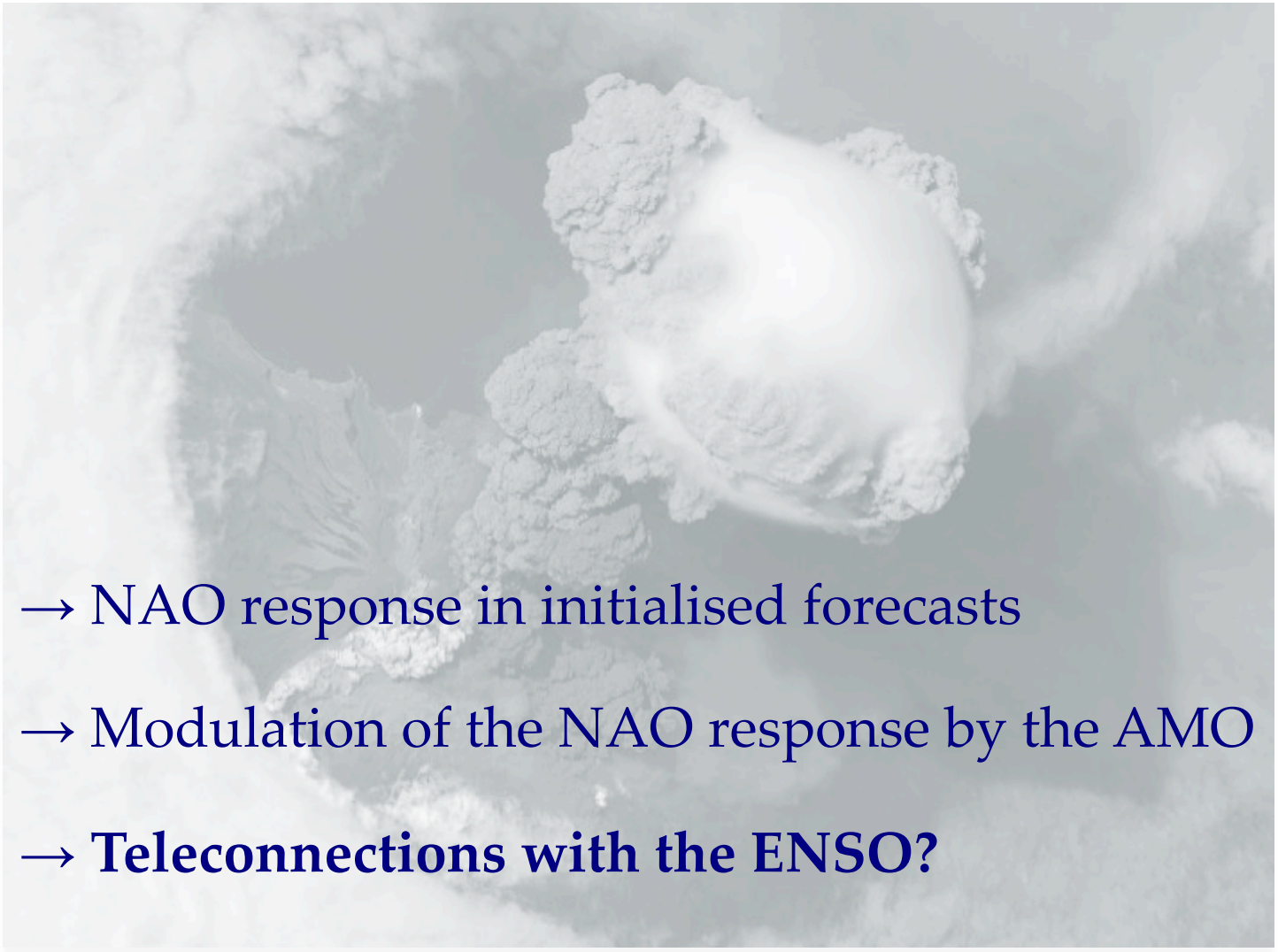


cold AMO



difference cold - warm AMO

3rd winter Z500 response to a Pinatubo-like eruption under extreme phases of the AMO in a CNRM-CM5 control simulation.



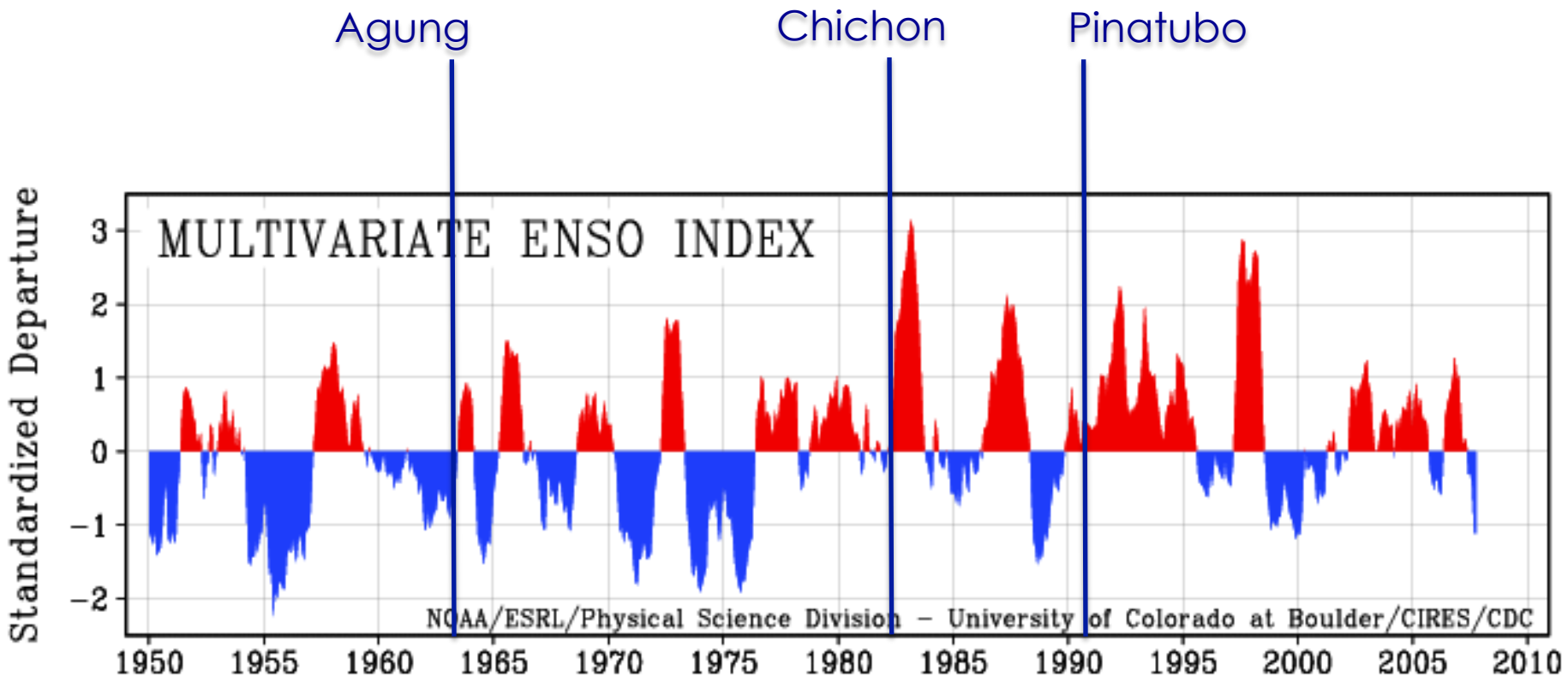
→ NAO response in initialised forecasts

→ Modulation of the NAO response by the AMO

→ **Teleconnections with the ENSO?**

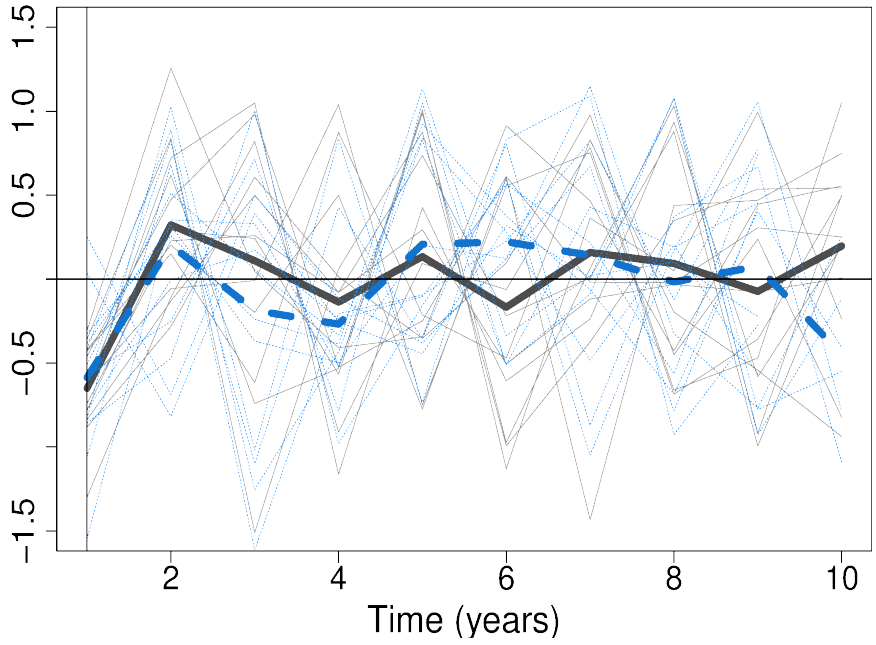
Volcanoes and ENSO

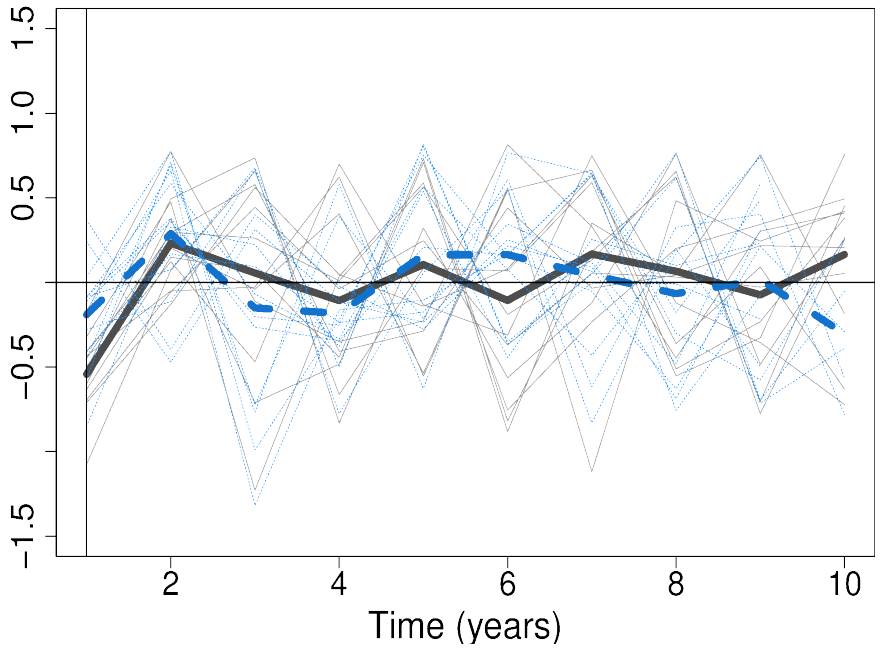
→ **Mixing between ENSO and volcanoes signals**



Volcanoes and ENSO

→ **Two ways to define the ENSO index:**





Winter ENSO defined as: (left) the 2m temperature anomaly in the nino 3.4 region (150°E-120°W, -5°S-5°S); (right) the 2m temperature difference between the nino 3.4 region and the tropics (20°S-20°N). Simulations including (blue) and excluding (black) a Pinatubo eruption the year 0, all initialised from climate conditions typical from a cold phase of the AMO.

Volcanoes and ENSO

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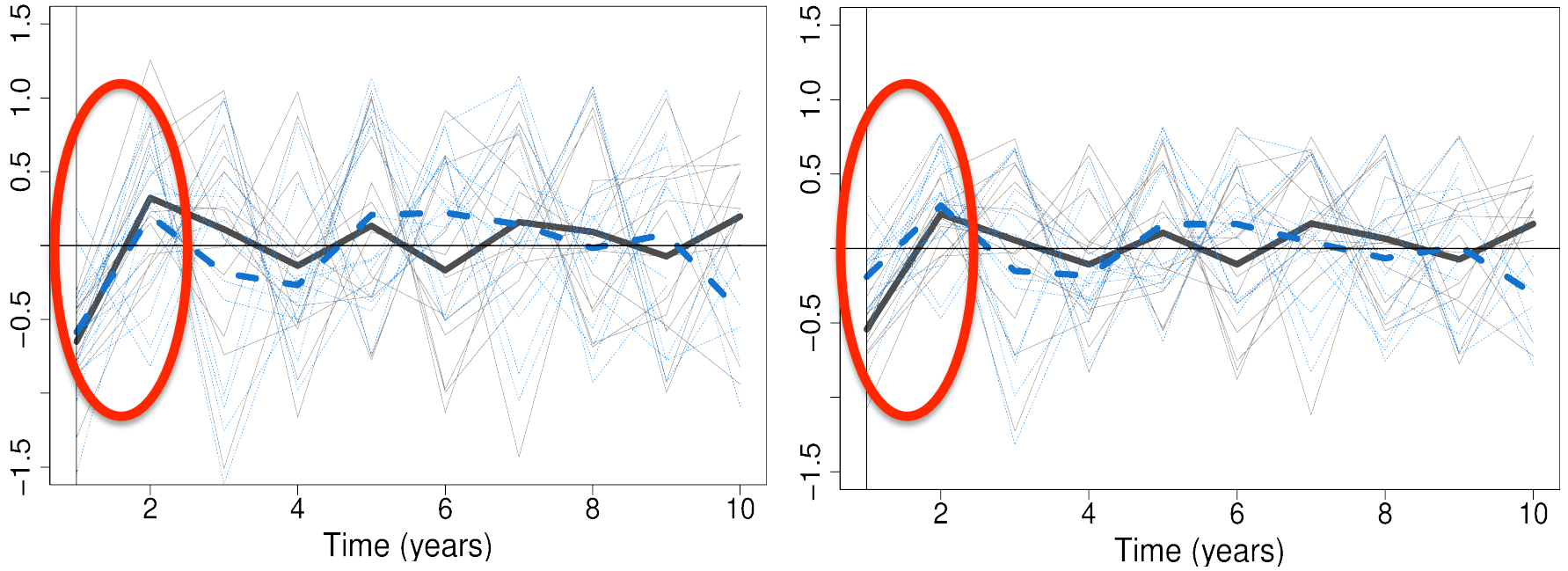
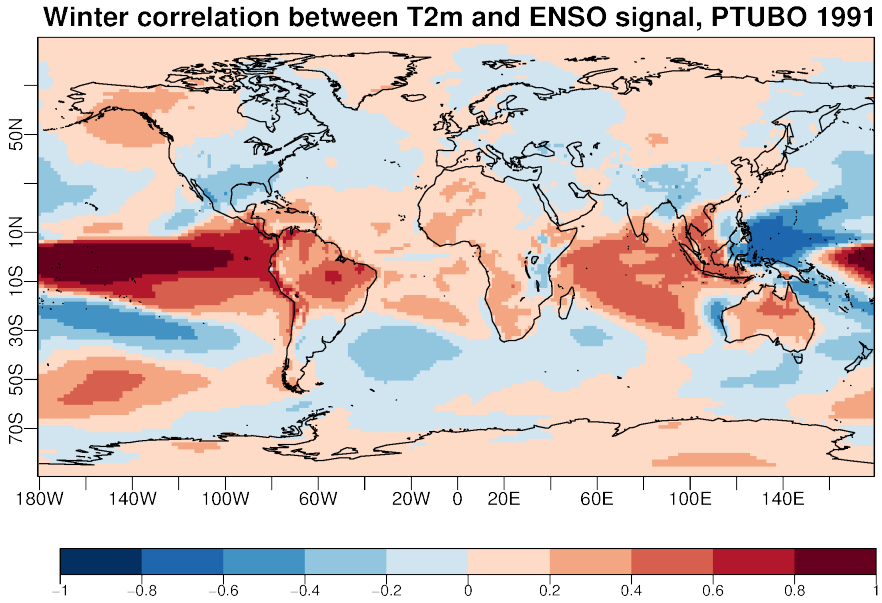
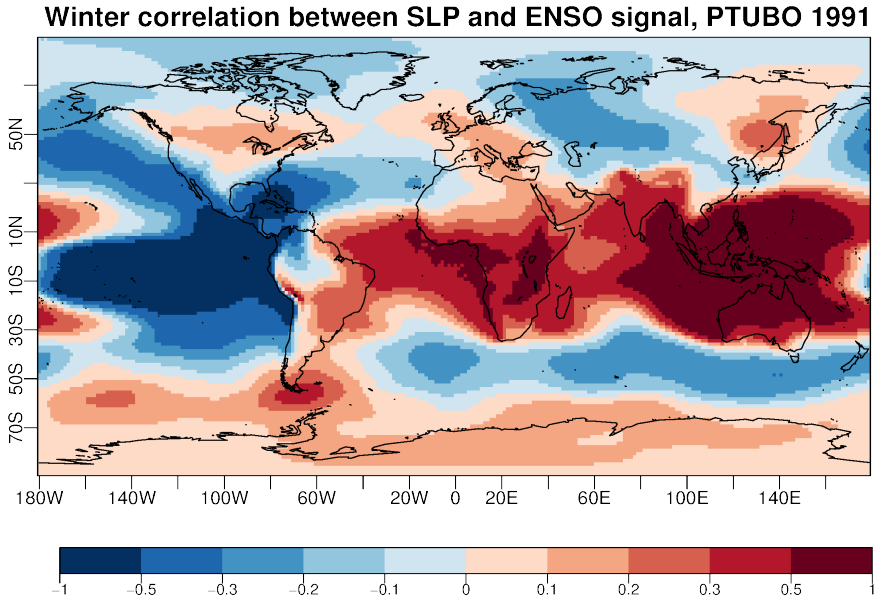


Winter ENSO defined as: (left) the 2m temperature anomaly in the nino 3.4 region (150°E-120°W, -5°S-5°S); (right) the 2m temperature difference between the nino 3.4 region and the tropics (20°S-20°N). Simulations including (blue) and excluding (black) a Pinatubo eruption the year 0, all initialised from climate conditions typical from a cold phase of the AMO.

Volcanoes and ENSO

→ Temperature and SLP correlations with the ENSO

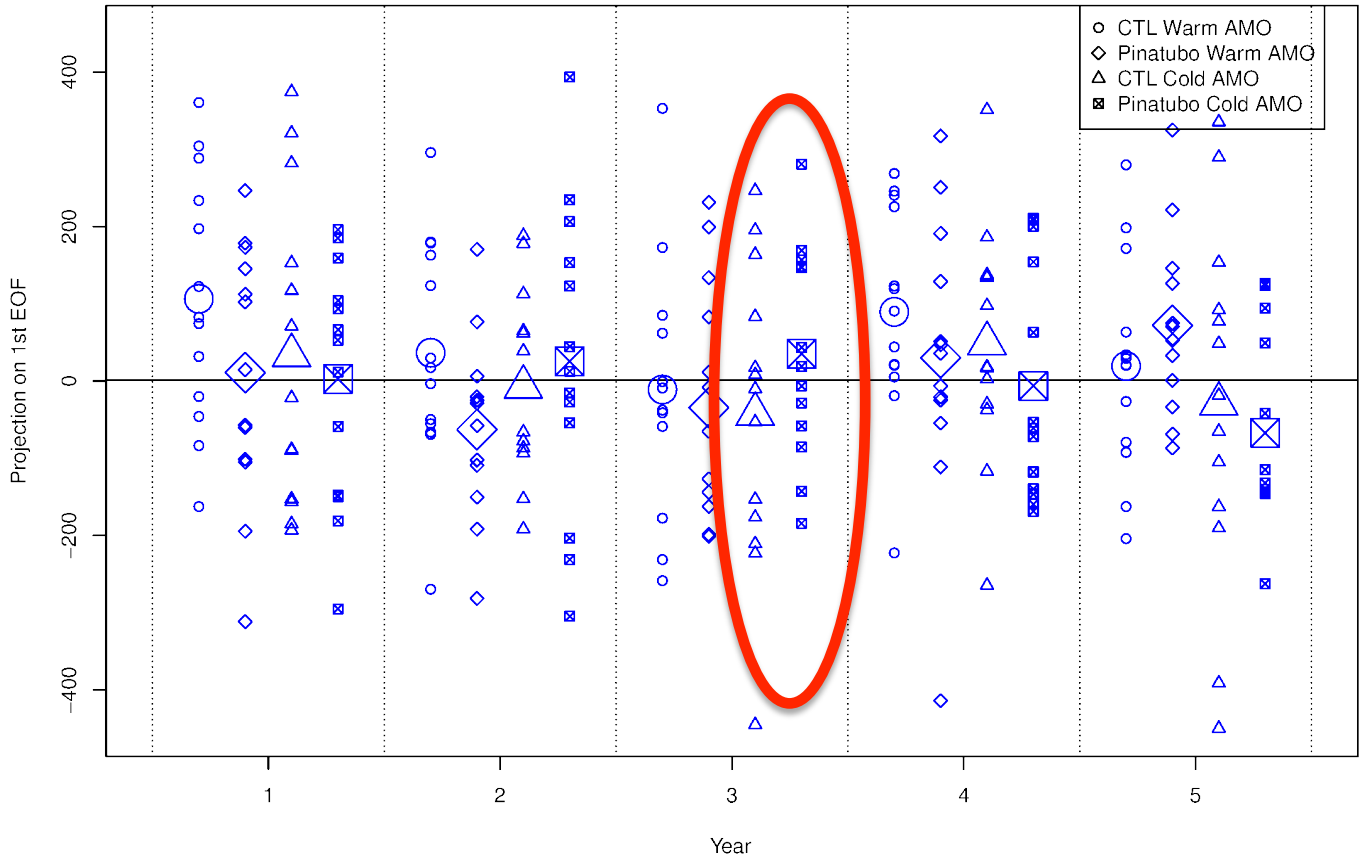




Correlation beteen ENSO index and temperature (left) and SLP (right)

Volcanoes and ENSO

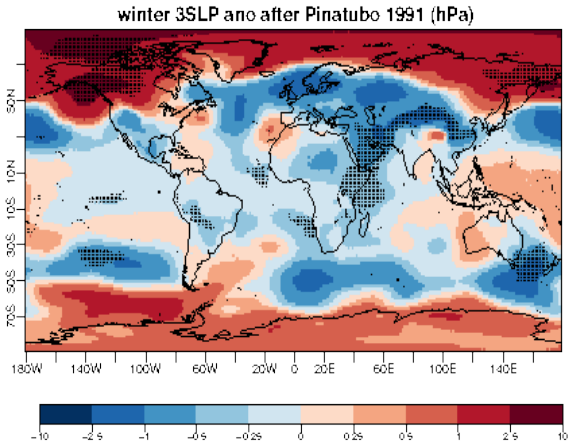
→ NAO+ signal the 3rd winter under a cold AMO no more significant!!!

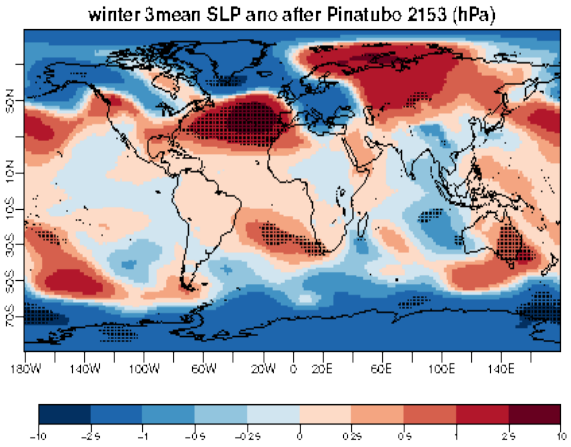


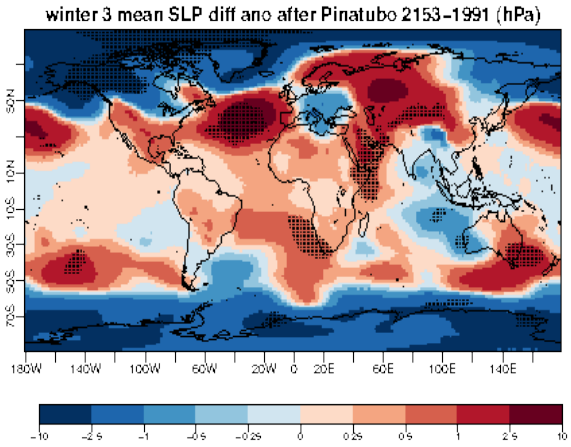
NAO index defined as projection on the first EOF of the SLP. Simulation significantly different from the others appear in red.

Volcanoes and ENSO

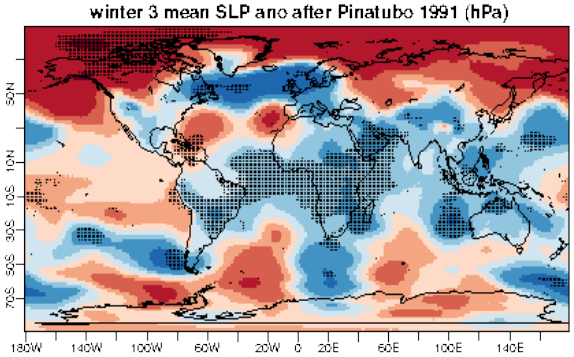
→ ENSO strengthen the NAO+ signal the 3rd winter after the eruption?



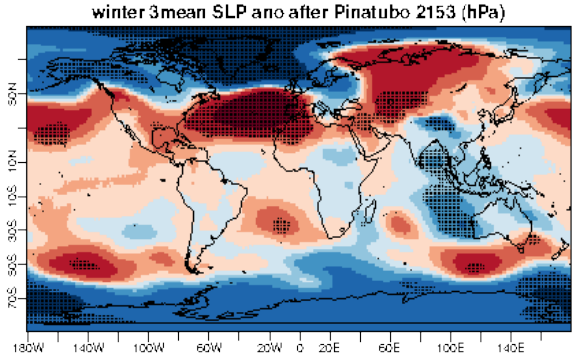




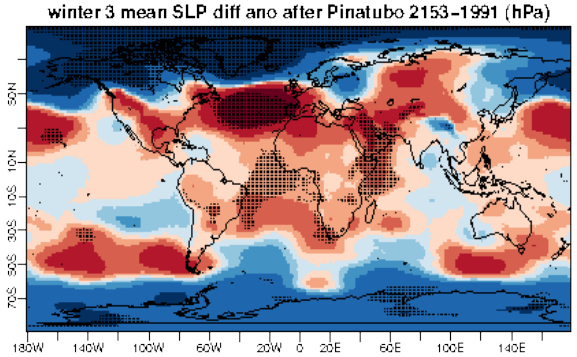
warm AMO



cold AMO



difference cold - warm AMO



SLP 3rd winter response to an eruption with (up) and without (bottom) the ENSO filter.

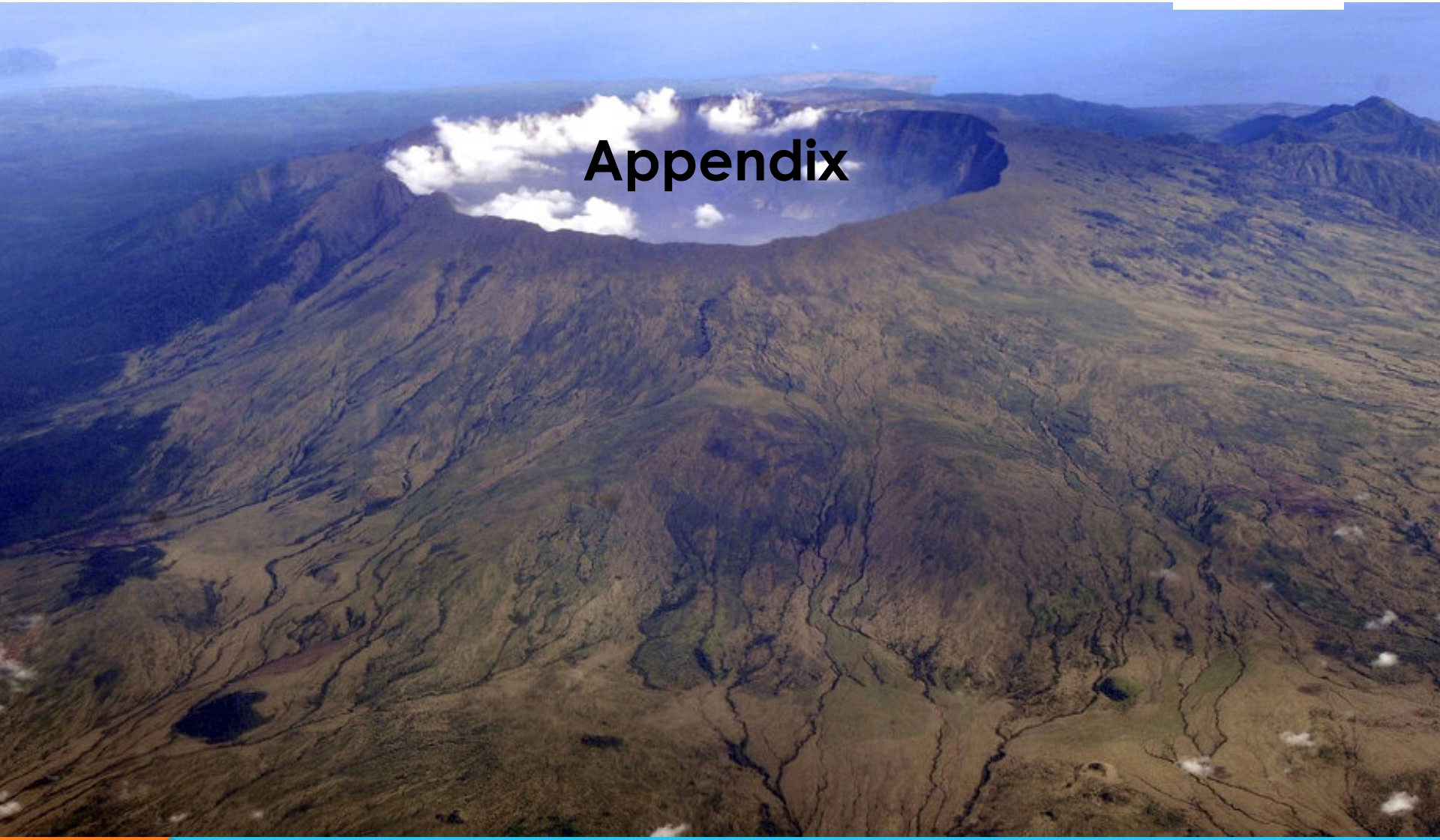
Conclusions

→ Both the EC-Earth forecasts and our CNRM-CM5 sensitivities experiments show a NAO+ signal the 3rd winter following a Pinatubo-like eruption, without any significant change of the NAO the 1st and the 2nd winters.

→ Such NAO+ signal is simulated only under cold AMO conditions.

→ Volcanic eruptions favour El Niño conditions during two years after an eruption. This ENSO response strengthen and make significant the NAO+ signal simulated the 3rd winter.

Any suggestions?



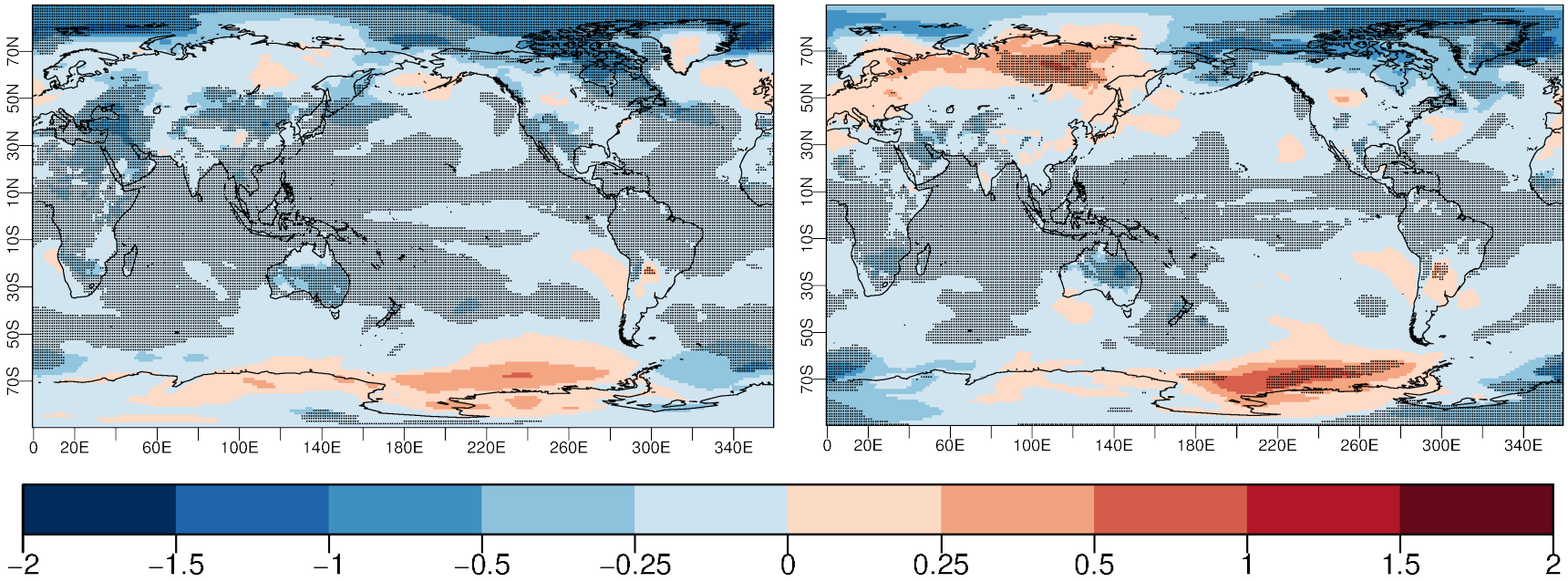
Appendix

Climate response to volcanoes

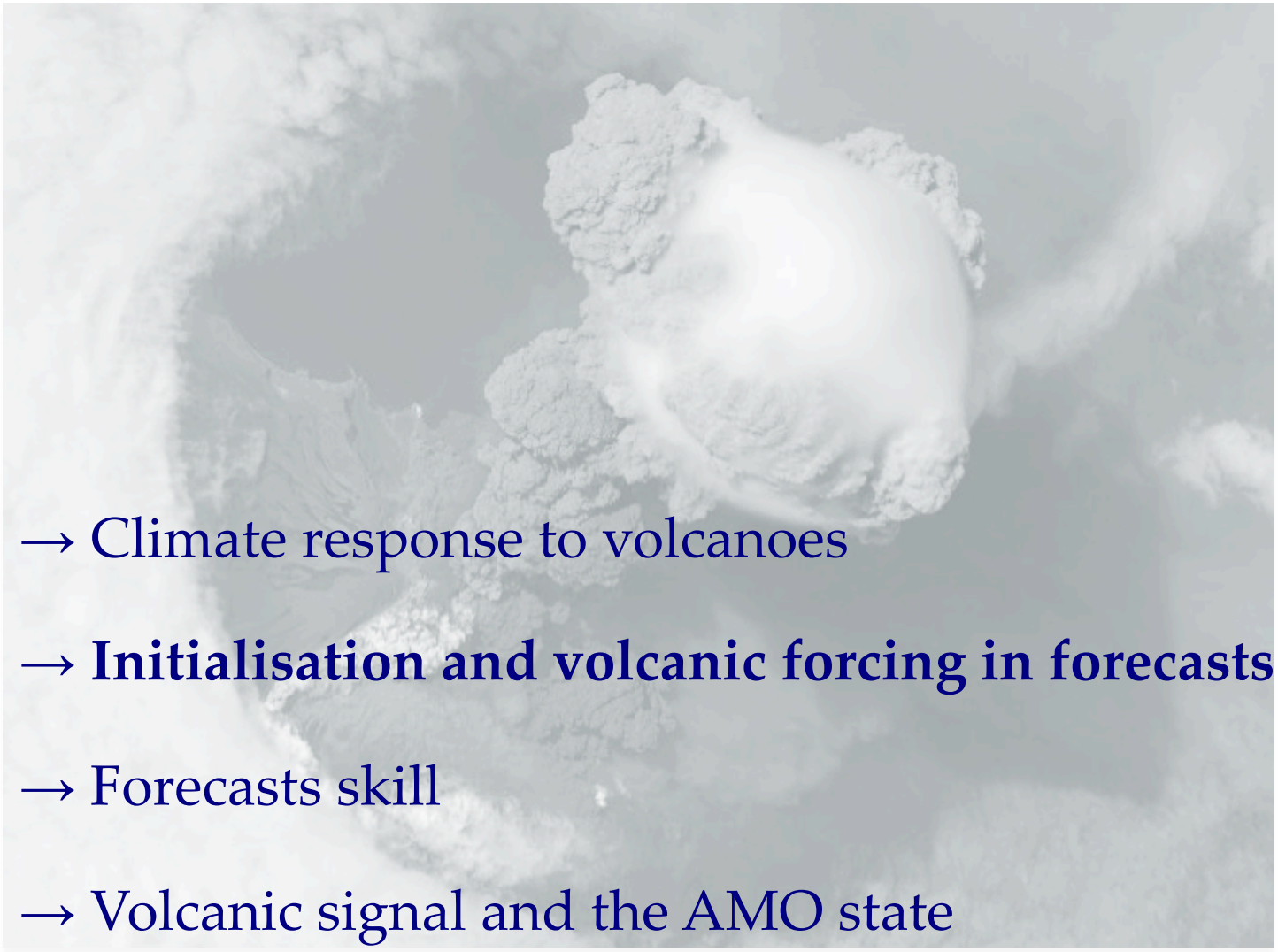
Sensitivity experiment with - without volcanoes

Years 1-3

Years 3-5



Surface temperature difference (°C). 3-year average after the 3 last major eruptions (Agung, 1963, Chichon, 1982 and Pinatubo, 1991). Difference has been computed between two 5-members hindcasts, one including and another excluding volcanic forcing of large eruptions, and appears shaded when significant with a 5% level.



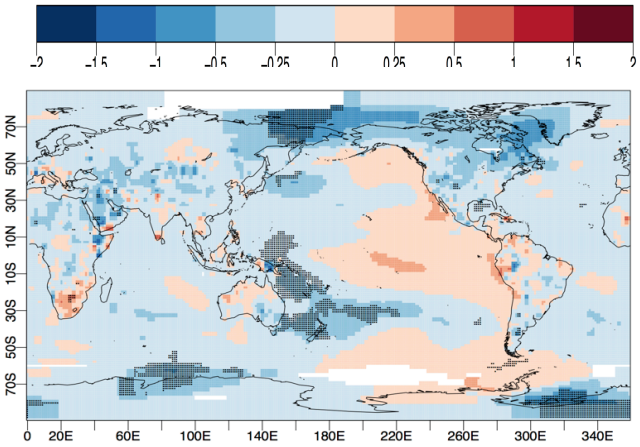
→ Climate response to volcanoes

→ **Initialisation and volcanic forcing in forecasts**

→ Forecasts skill

→ Volcanic signal and the AMO state

Initialisation and volcanoes

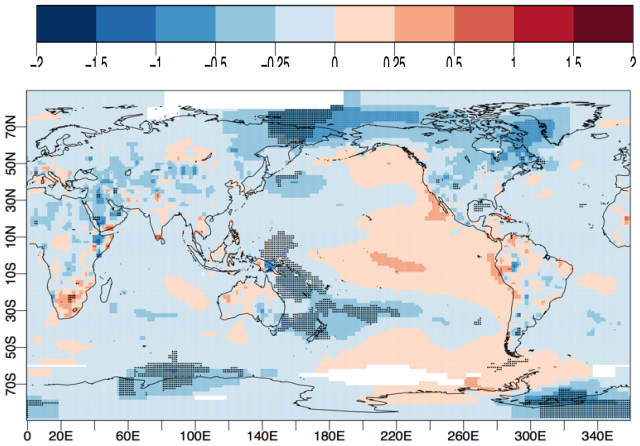


Observation

Surface temperature anomalies over forecast years 1-3 averaged after the last 3 major eruptions.

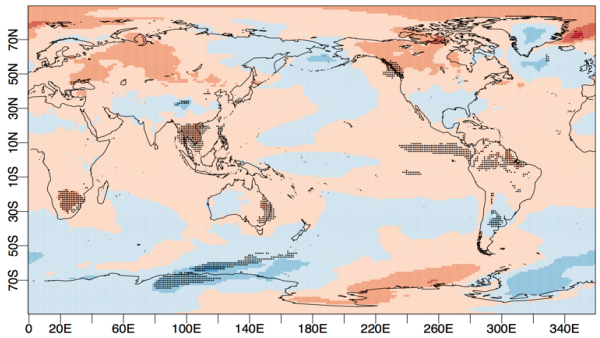
Surface temperature anomalies over forecast years 1-3 after the last 3 major eruptions. Anomalies are averaged over 3 start dates (and 5 members for the simulations).

Initialisation and volcanoes



Observation

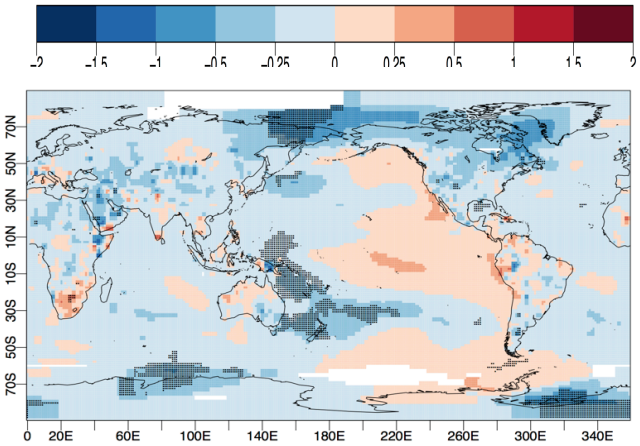
Surface temperature anomalies over forecast years 1-3 averaged after the last 3 major eruptions.



Initialisation and no volcanic forcing

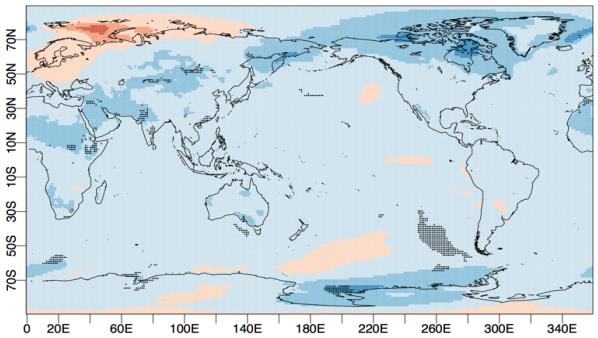
Surface temperature anomalies over forecast years 1-3 after the last 3 major eruptions. Anomalies are averaged over 3 start dates (and 5 members for the simulations).

Initialisation and volcanoes

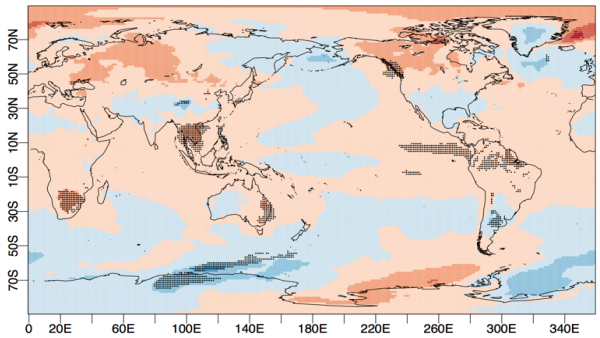


Observation

Surface temperature anomalies over forecast years 1-3 averaged after the last 3 major eruptions.



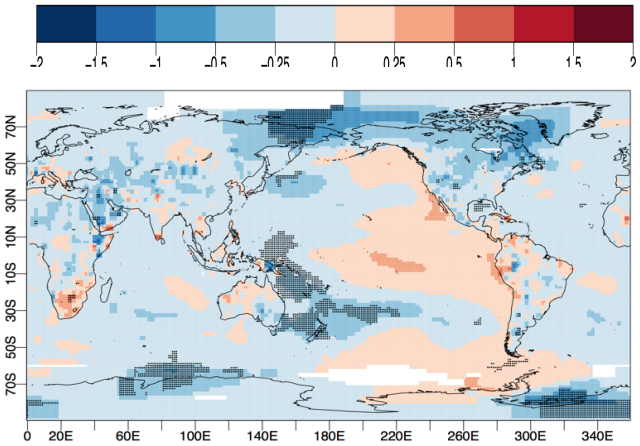
No initialisation and volcanic forcing



Initialisation and no volcanic forcing

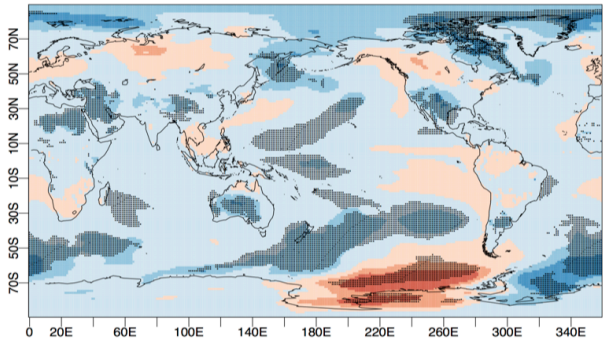
Surface temperature anomalies over forecast years 1-3 after the last 3 major eruptions. Anomalies are averaged over 3 start dates (and 5 members for the simulations).

Initialisation and volcanoes

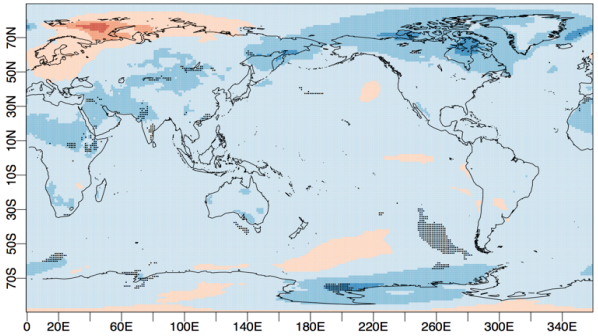


Observation

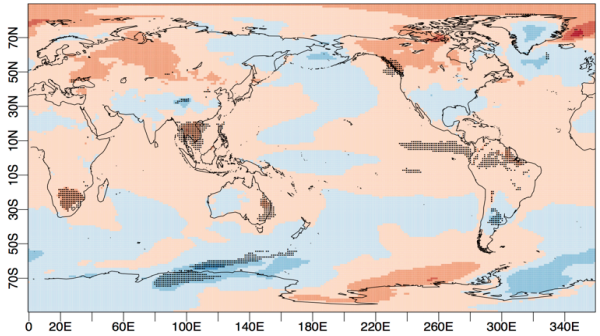
Surface temperature anomalies over forecast years 1-3 averaged after the last 3 major eruptions.



Initialisation and volcanic forcing



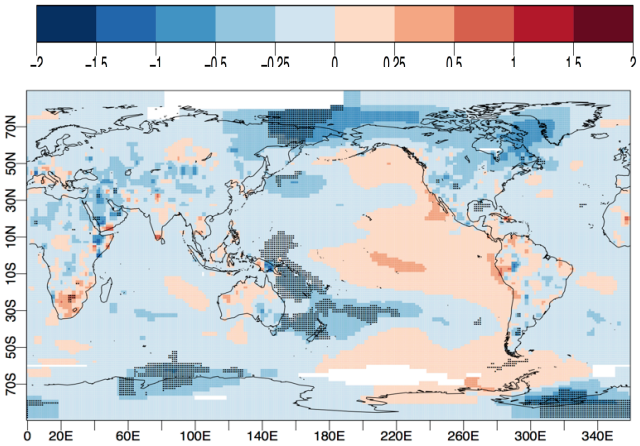
No initialisation and volcanic forcing



Initialisation and no volcanic forcing

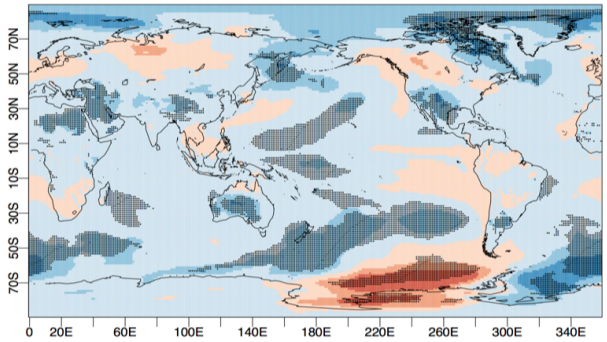
Surface temperature anomalies over forecast years 1-3 after the last 3 major eruptions. Anomalies are averaged over 3 start dates (and 5 members for the simulations).

Initialisation and volcanoes

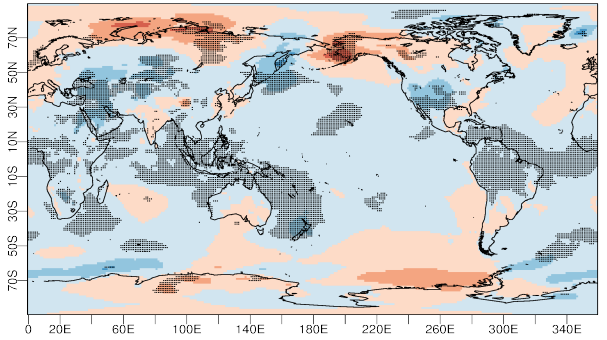


Observation

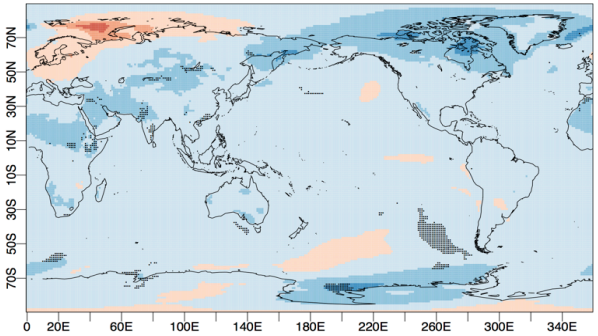
Surface temperature anomalies over forecast years 1-3 averaged after the last 3 major eruptions.



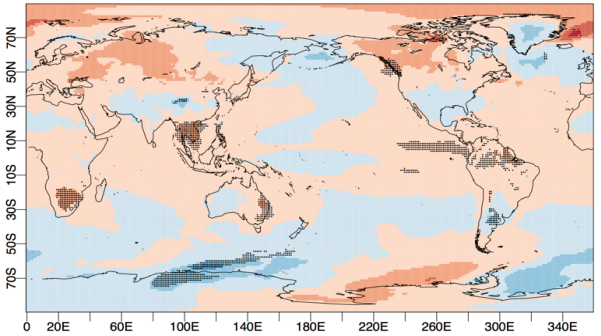
Initialisation and volcanic forcing



Initialisation and idealized volcanic forcing

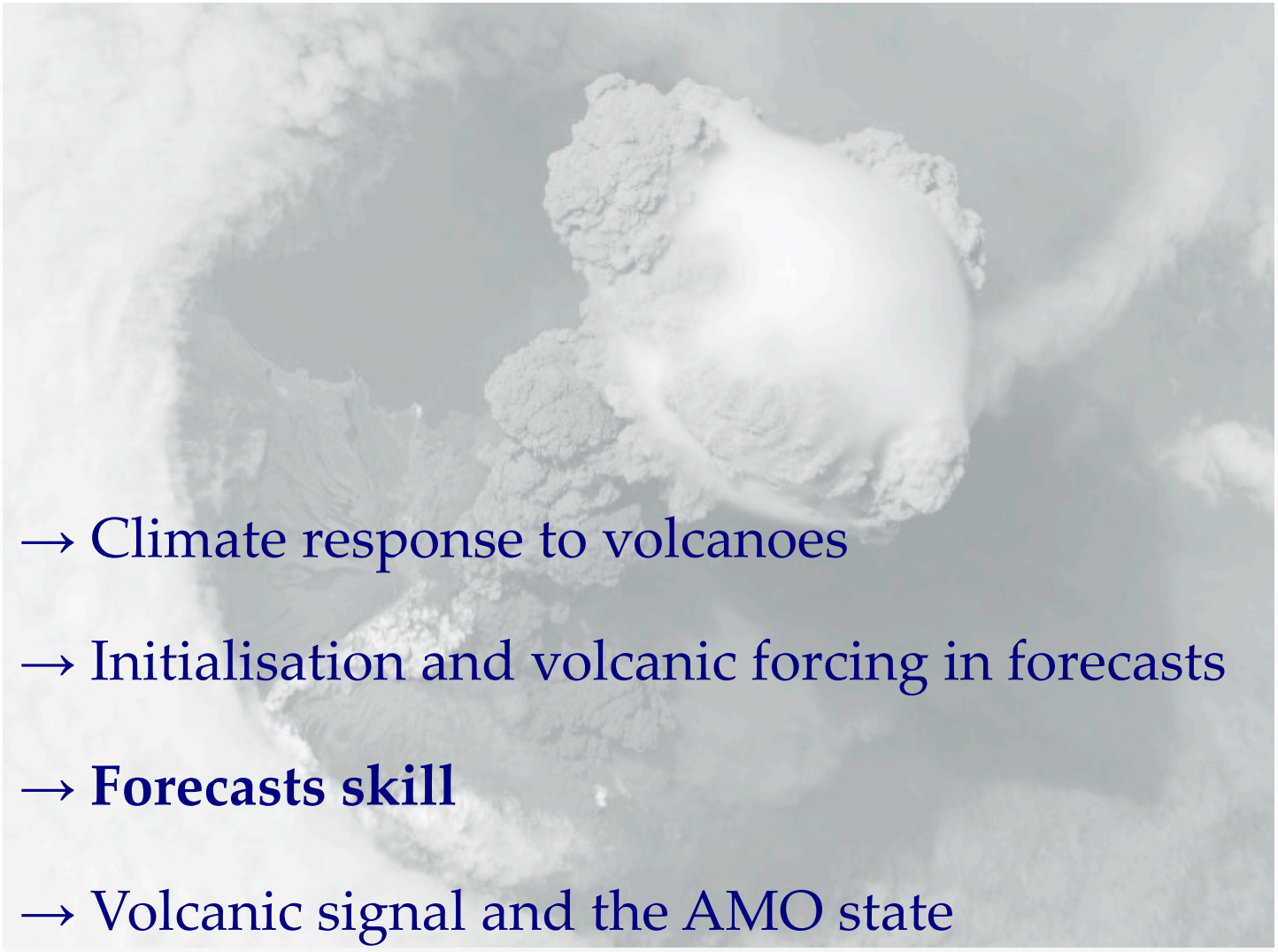


No initialisation and volcanic forcing



Initialisation and no volcanic forcing

Surface temperature anomalies over forecast years 1-3 after the last 3 major eruptions. Anomalies are averaged over 3 start dates (and 5 members for the simulations).



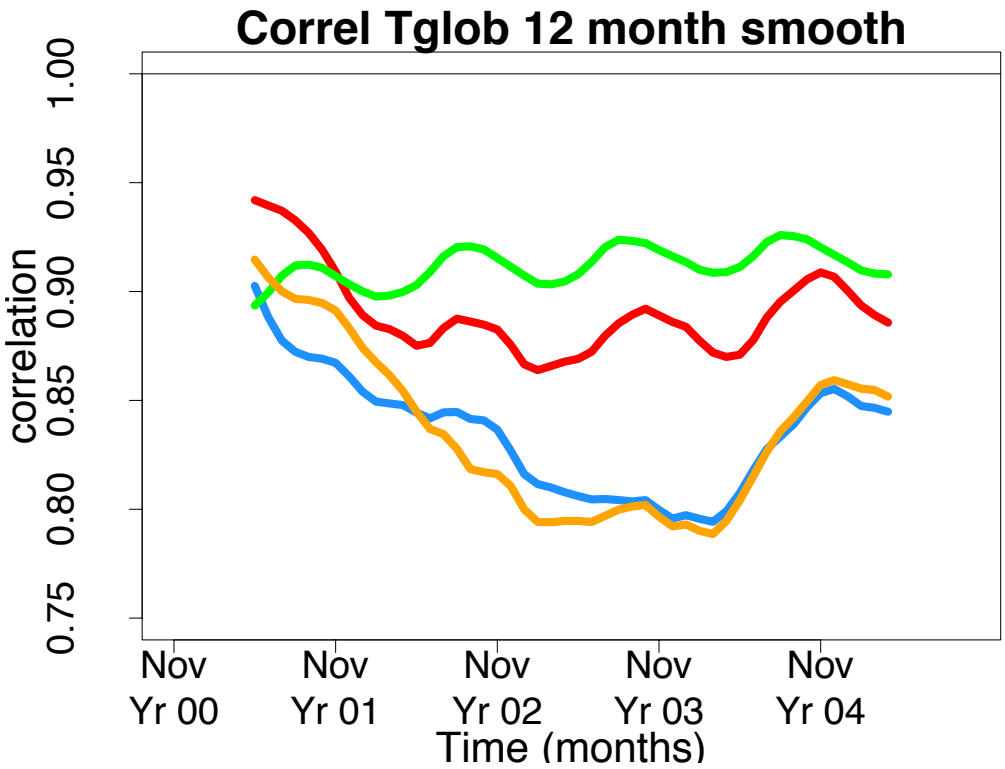
→ Climate response to volcanoes

→ Initialisation and volcanic forcing in forecasts

→ **Forecasts skill**

→ Volcanic signal and the AMO state

Correlation and RMSE



Volcanoes without initialisation

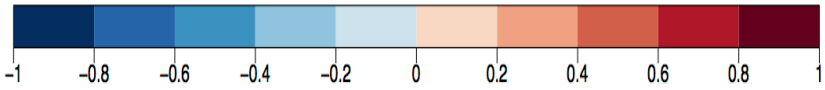
Volcanoes with initialisation

Initialisation without volcanoes

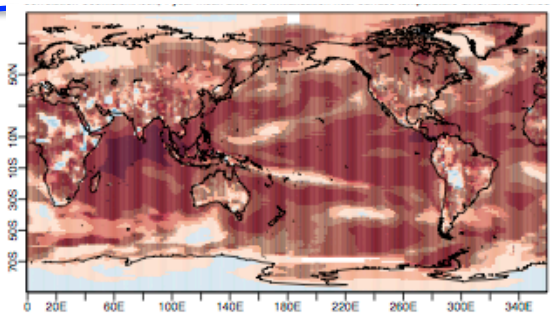
Initialisation with idealized volcanic forcing

Correlation for 12 and 36 month smoothed running mean anomalies. Differences between hindcasts are not statistically significant.

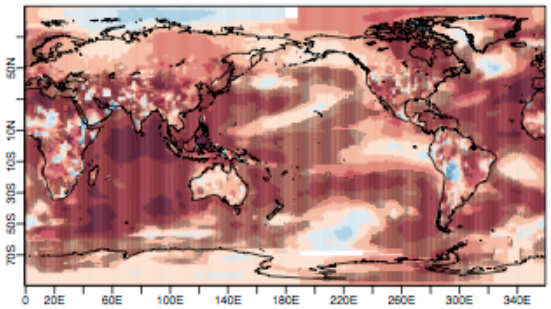
Correlation and RMSE



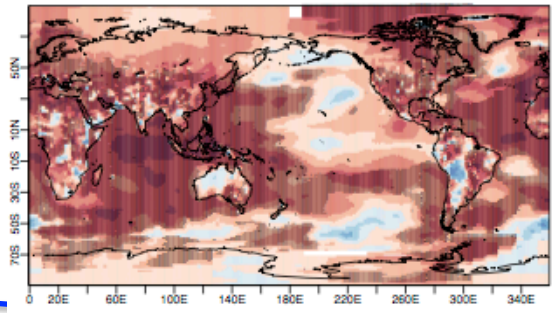
Correlation with initialisation and volcanoes



Y 1

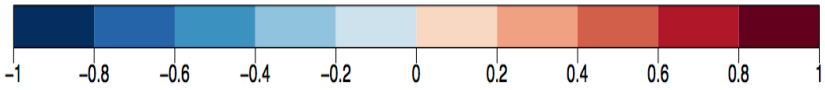


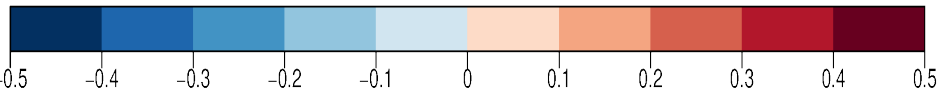
Y 1-3



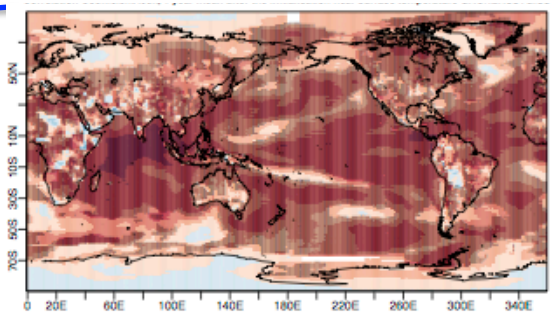
Y 3-5

Correlation and RMSE





Correlation with initialisation and volcanoes



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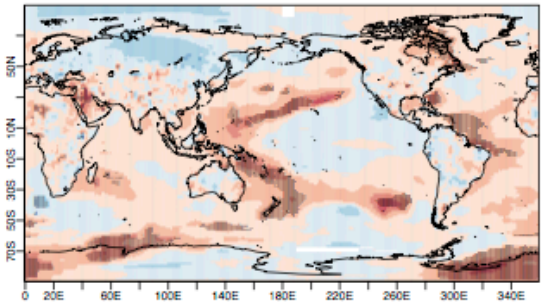
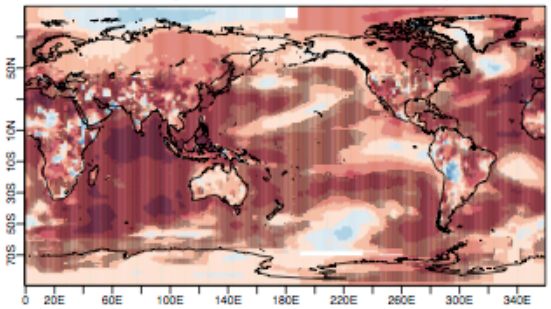
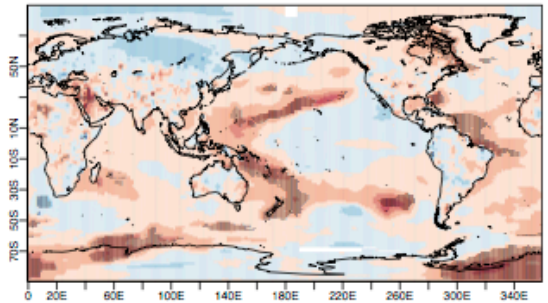
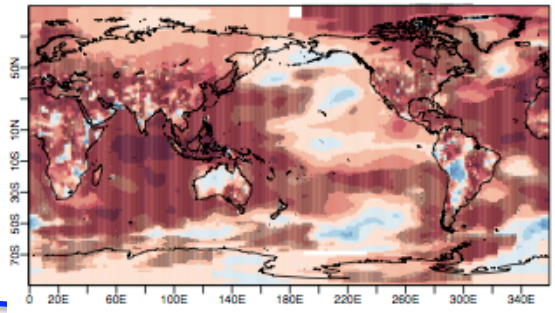


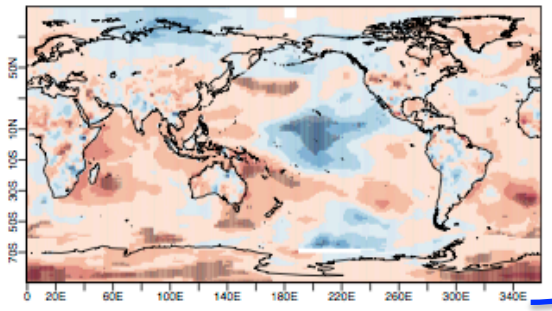


Y 1-3



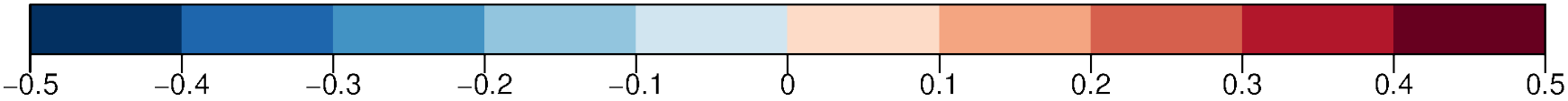


Y 3-5

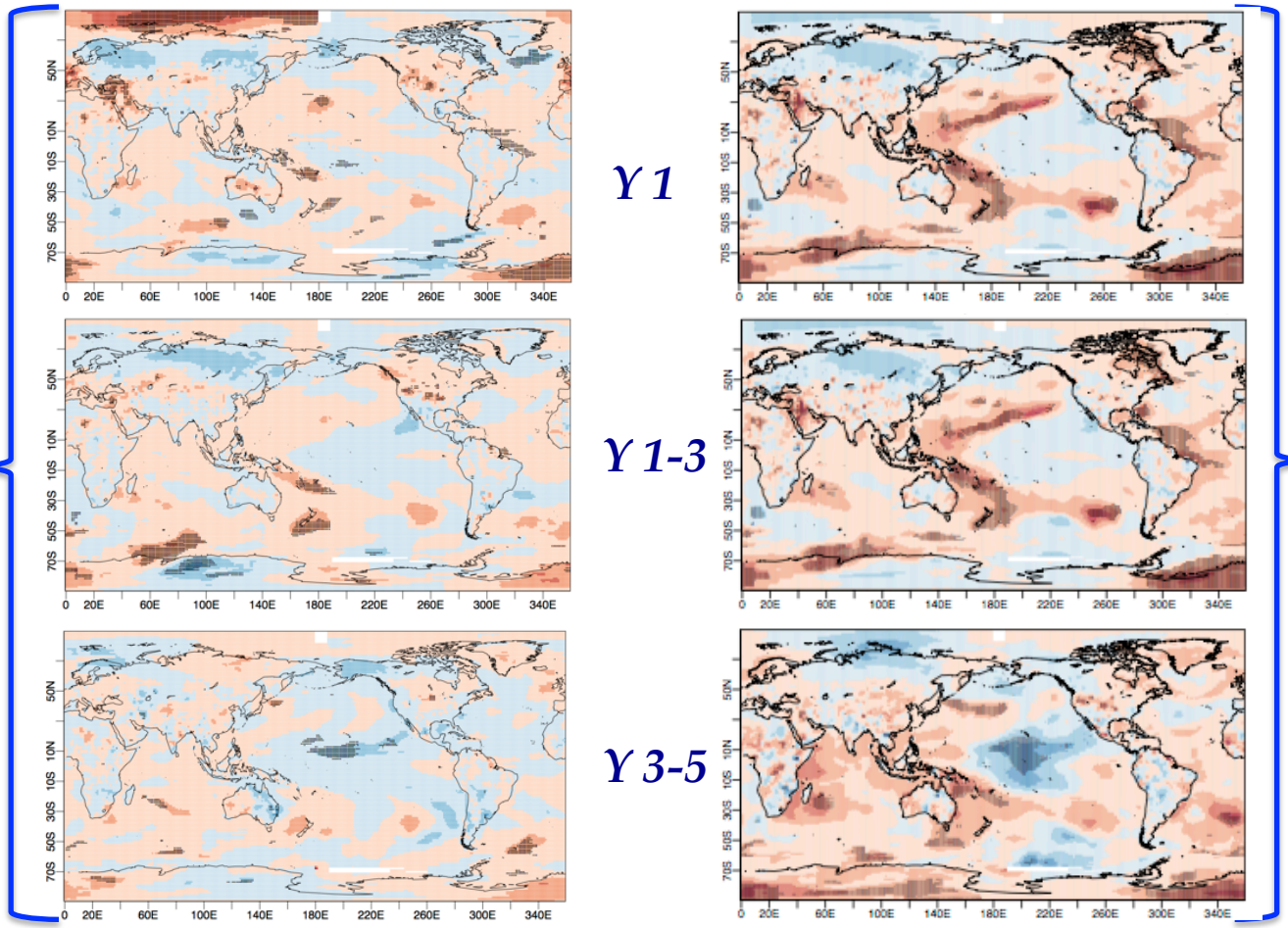


Correlation increase with observed volcanic forcing

Idealized forcing

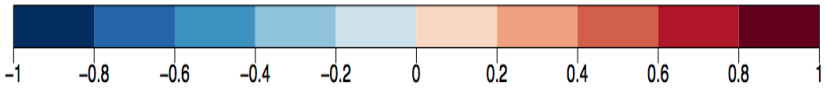


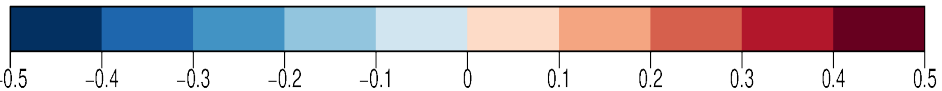
Correlation increase with idealized volcanic forcing



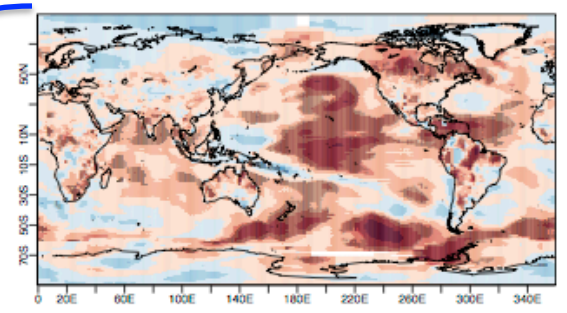
Correlation increase with observed volcanic forcing

Correlation and RMSE

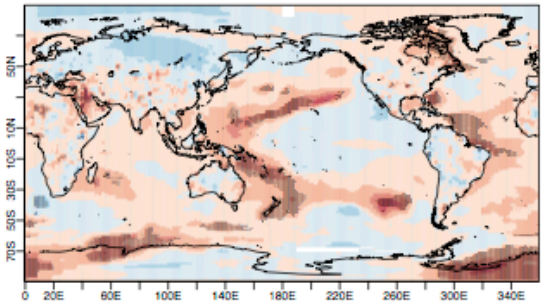


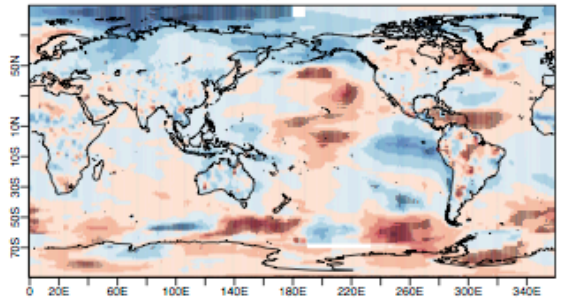


Correlation increase with initialisation

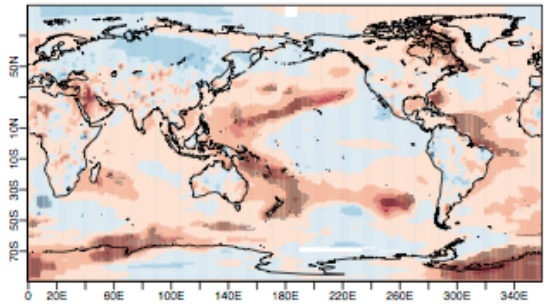


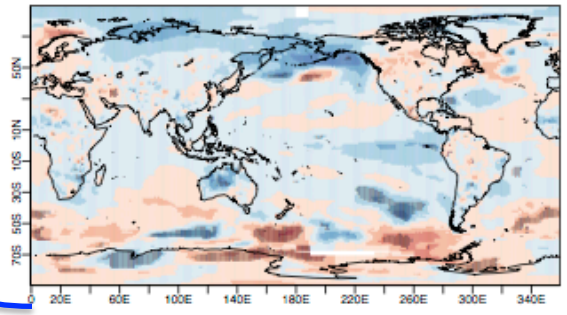
Y 1



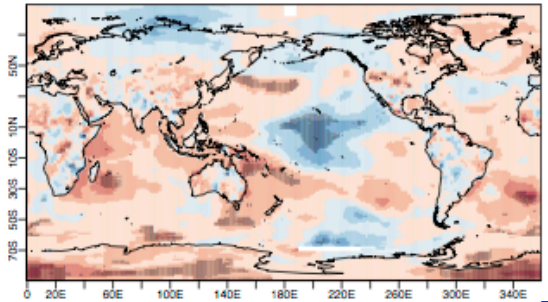


Y 1-3

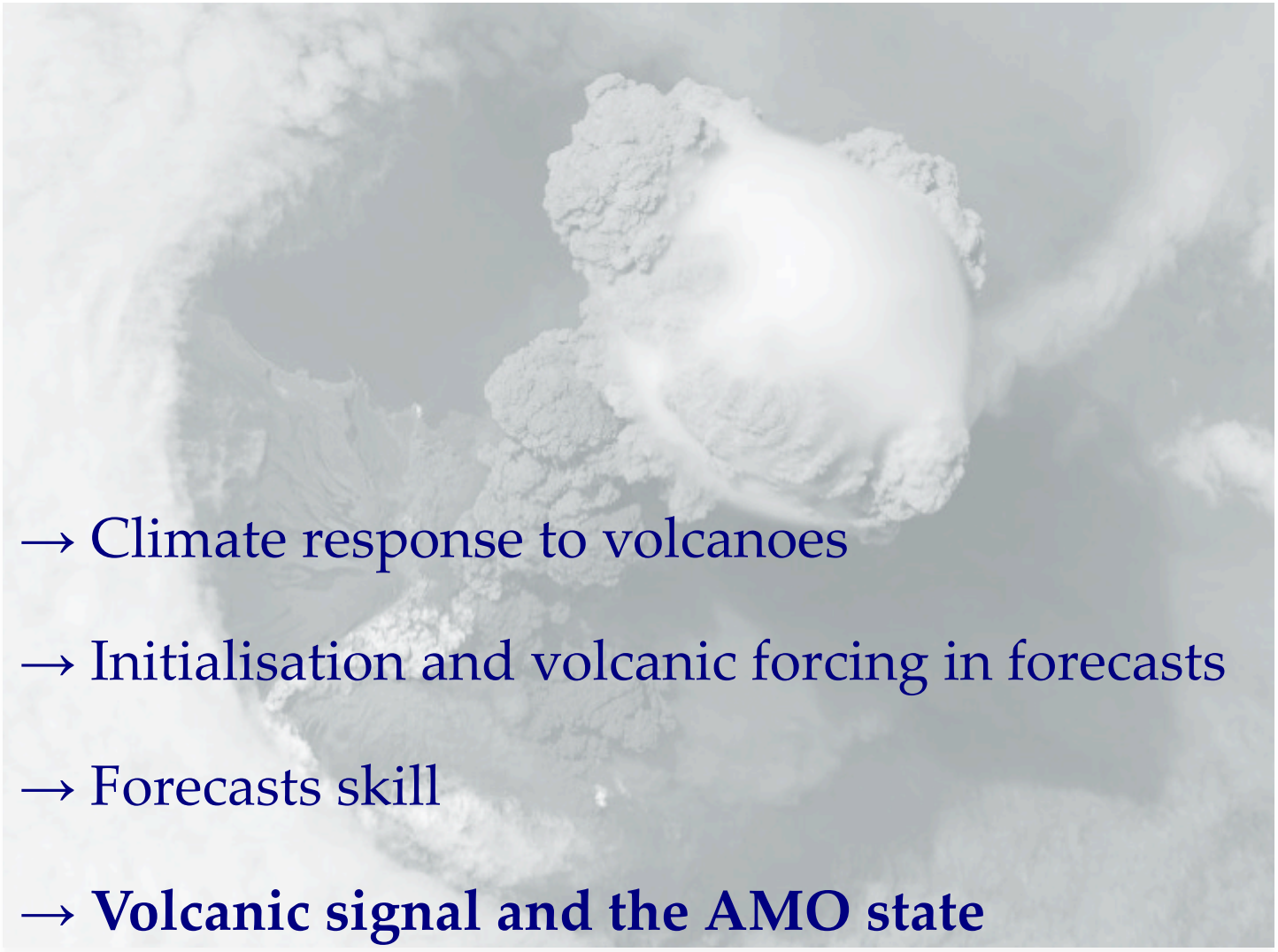




Y 3-5



Correlation increase with observed volcanic forcing



→ Climate response to volcanoes

→ Initialisation and volcanic forcing in forecasts

→ Forecasts skill

→ **Volcanic signal and the AMO state**

Conclusion

→ Last major eruptions induced a strong cooling over the tropics and the Northern continent that was partly overwhelmed by internal variability.

→ Evaluating the performances of climate forecast systems cannot be done without considering large eruptions that occurred during the last decades.

→ The EC-Earth historical simulation has higher skill than hindcasts.

→ Volcanic forcing in hindcasts is associated to an increase of skill for surface temperature in Western Pacific, tropical Atlantic and Indian Ocean.

→ A real-time forecast of the next volcanic eruption require the design of an idealized forcing.

→ EC-Earth has no skill to predict the NAO, even after volcanic eruptions.

→ The CNRM-CM5 model simulates a NAO+ response the third winter following a Pinatubo eruption when the AMO is cold.

Winter response

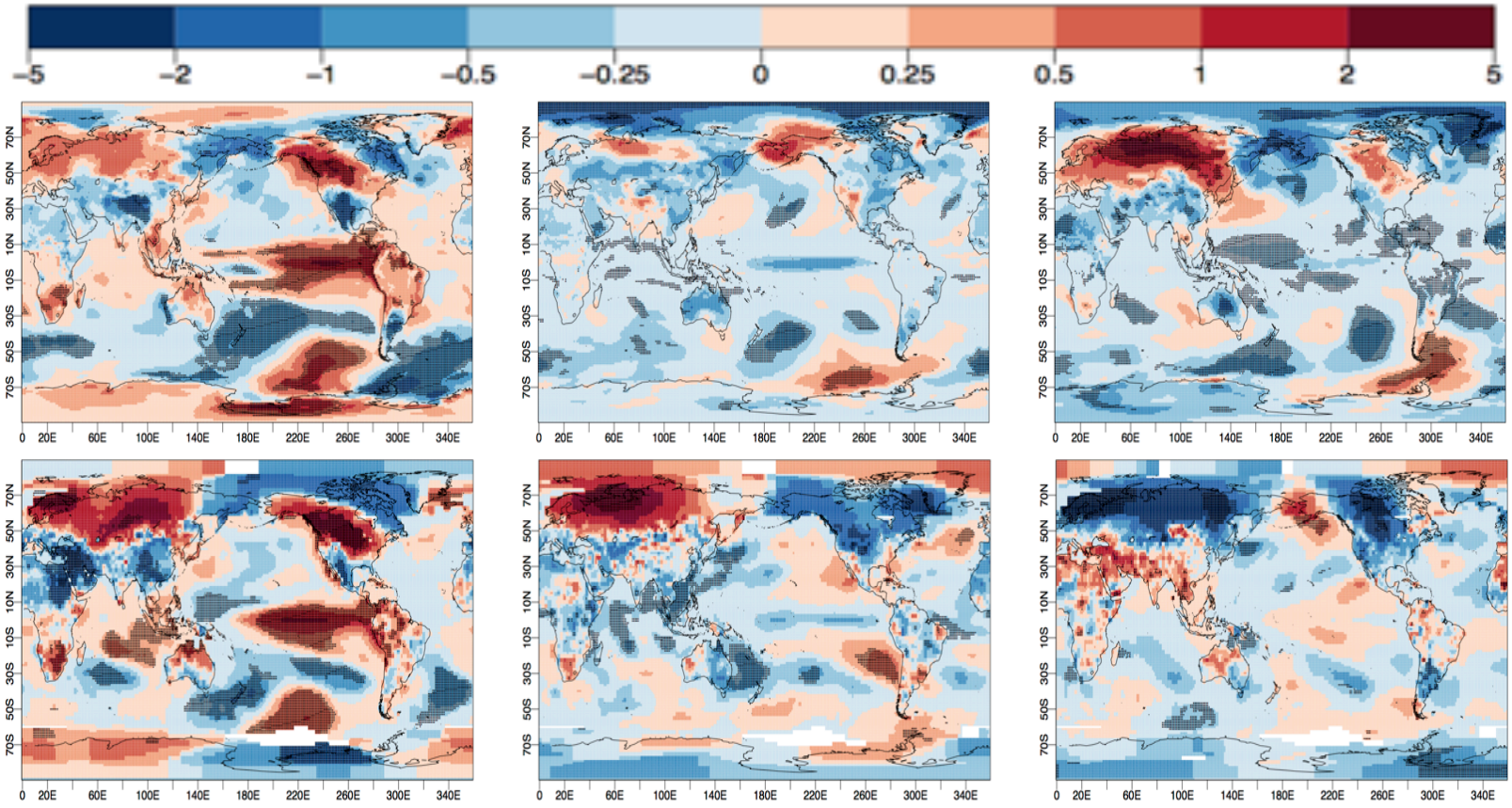
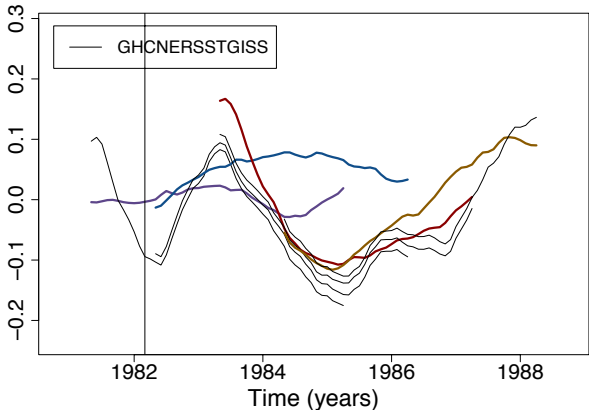


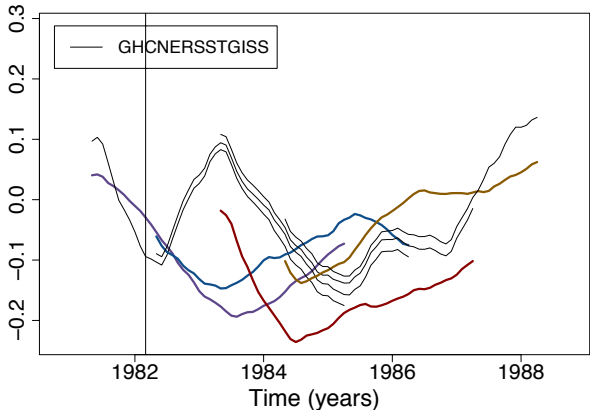
Figure 5: Winter surface temperature anomalies after the last 3 major eruptions. Anomalies are averaged over 3 dates (and 5 members for the simulations). Top: forecast; bottom: observations

Initialisation and volcanoes

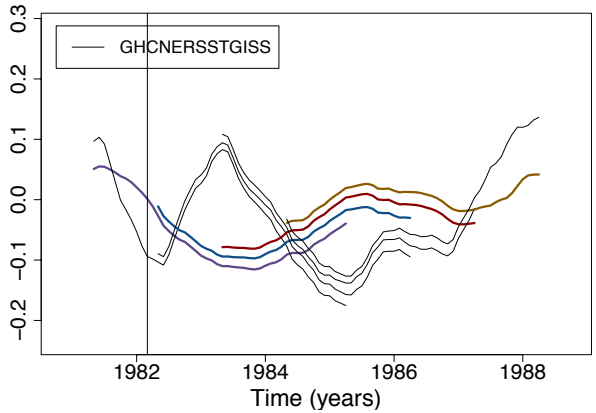
El Chichón



Initialisation without volcanoes



Initialisation with volcanoes

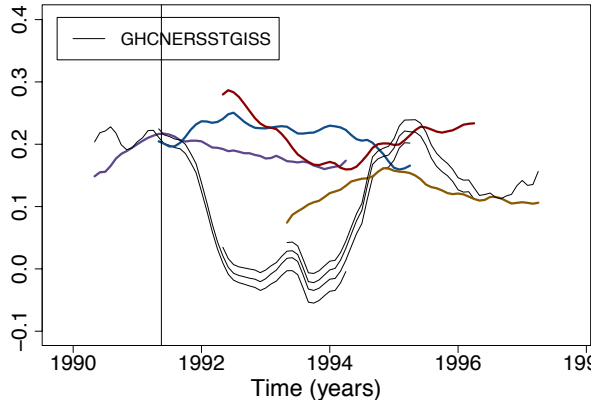


Volcanoes without initialisation

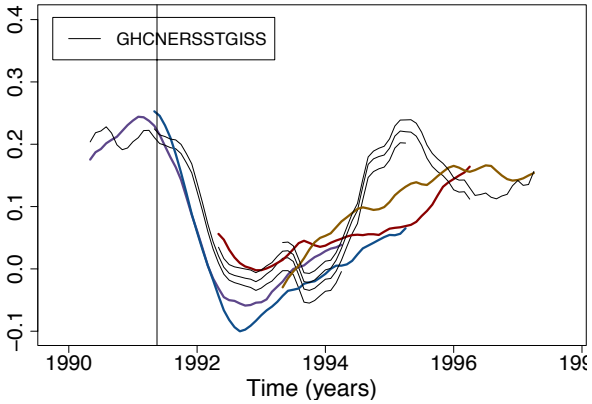
Surface temperature anomalies forecast for 4 different startdates around the El Chichón eruption (blue and purple start before the eruption; red and yellow start after the eruption). Hindcasts start in November. Observations anomalies (black) are computed with climatologies varying along the forecast time, data from ERSST and GHCN (GISS). Anomalies are smoothed with a 12-month running mean.

Initialisation and volcanoes

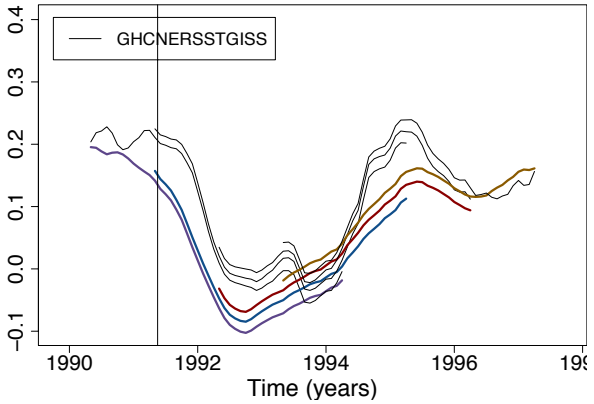
Pinatubo



Initialisation without volcanoes



Initialisation with volcanoes

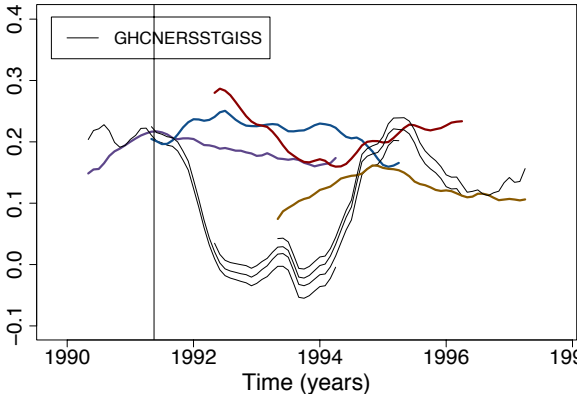


Volcanoes without initialisation

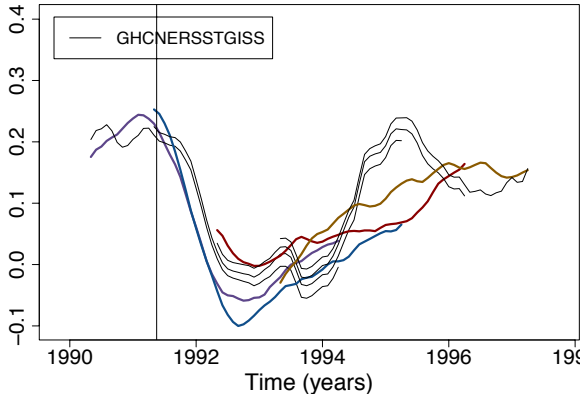
Surface temperature anomalies forecast for 4 different startdates around the Pinatubo eruption (blue and purple start before the eruption; red and yellow start after the eruption). Hindcasts start in November. Anomalies observations (black) are computed with climatologies varying along the forecast time, data from ERSST and GHCN (GISS). Anomalies are smoothed with a 12-month running mean.

Initialisation and volcanoes

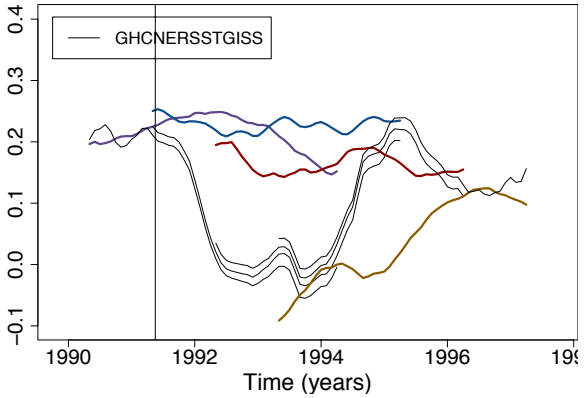
Pinatubo



Initialisation without volcanoes



Initialisation with volcanoes

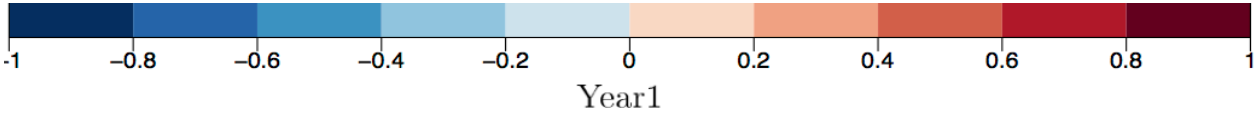


Initialisation with idealized volcanoes

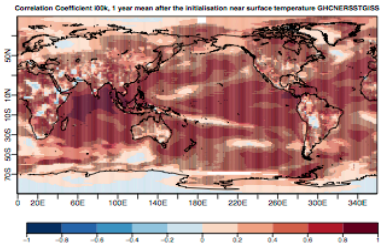
Surface temperature anomalies forecast for 4 different startdates around the Pinatubo eruption (blue and purple start before the eruption; red and yellow start after the eruption). Hindcasts start in November. Anomalies observations (black) are computed with climatologies varying along the forecast time, data from ERSST and GHCN (GISS). Anomalies are smoothed with a 12-month running mean. Idealized forcing is computed as the current stratospheric aerosol load at the startdate decreasing toward "background level" after a one year exponential decay.

Appendix

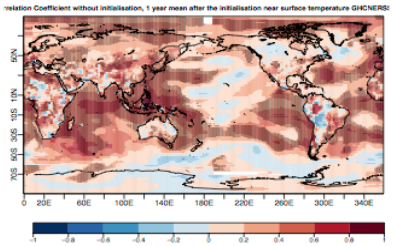
→ **Skill increase with initialisation**



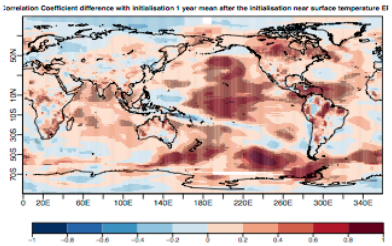
Year1



initialisation and all forcings

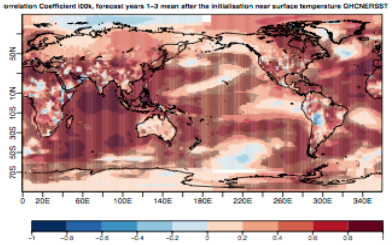


without initialisation

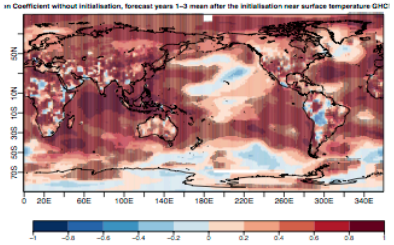


additional cor with initialisation

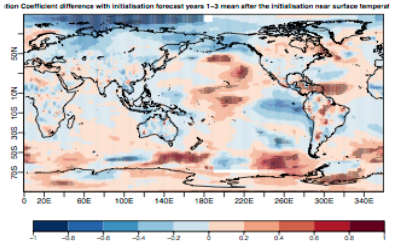
Year 1-3



initialisation and all forcings

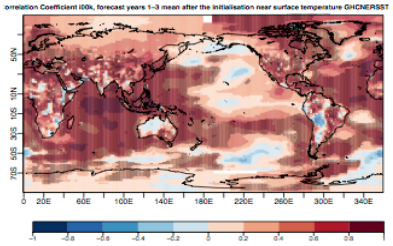


without initialisation

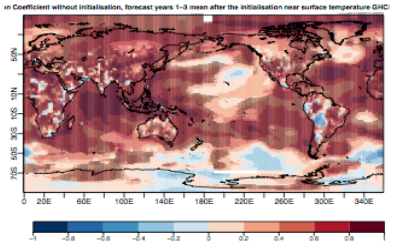


additional cor with initialisation

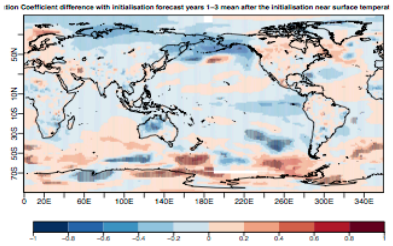
Year3-5



initialisation and all forcings



without initialisation

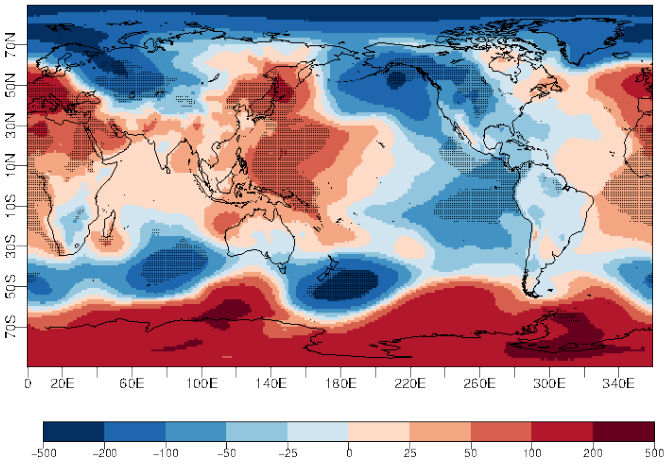


additional cor with initialisation

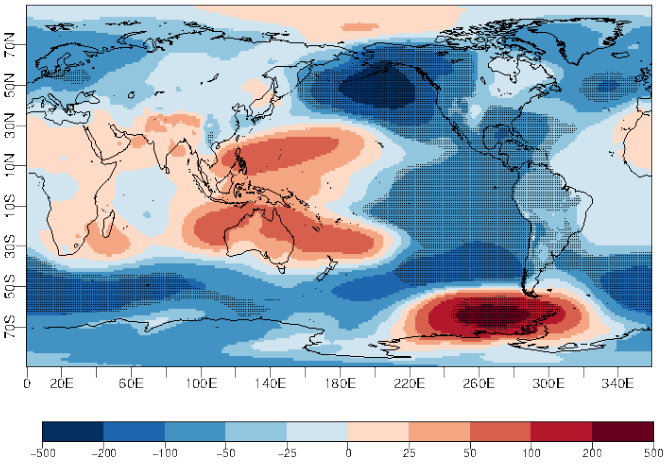
Appendix

→ **First year pressure anomalies**

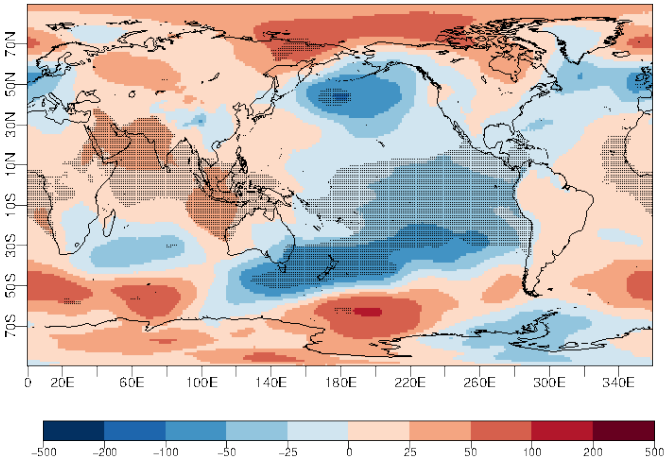
Year 1



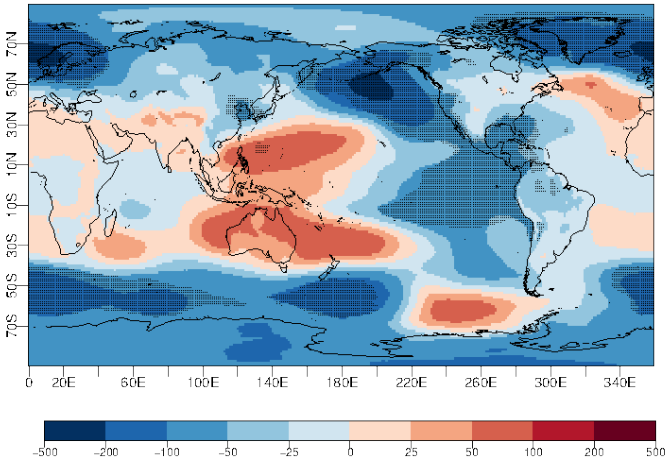
Observations



Initialisation and volcanoes



volcanoes without initialisation

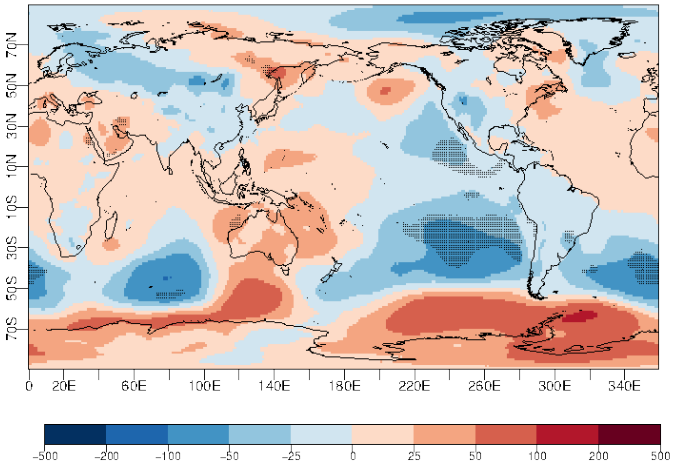


initialisation without volcanoes

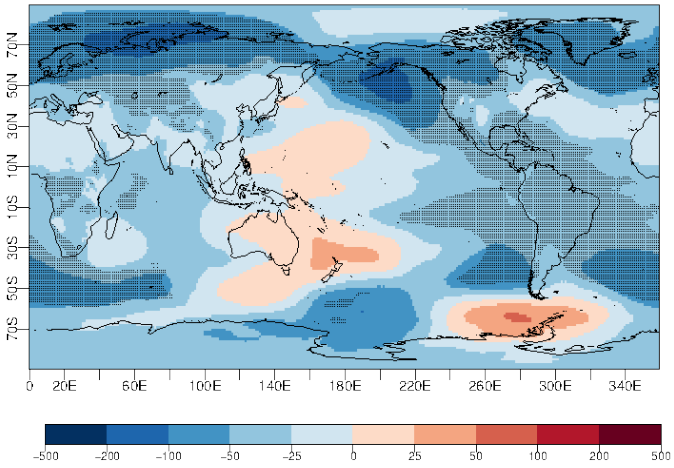
Appendix

→ **Years 1-3 pressure anomalies**

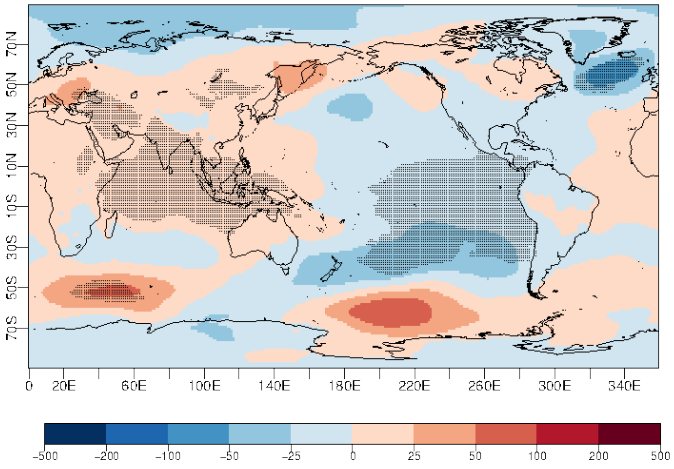
Years 1-3



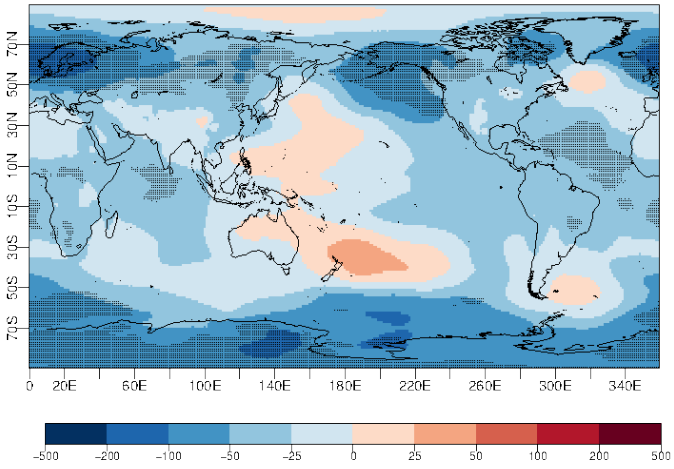
Observations



Initialisation and volcanoes



volcanoes without initialisation

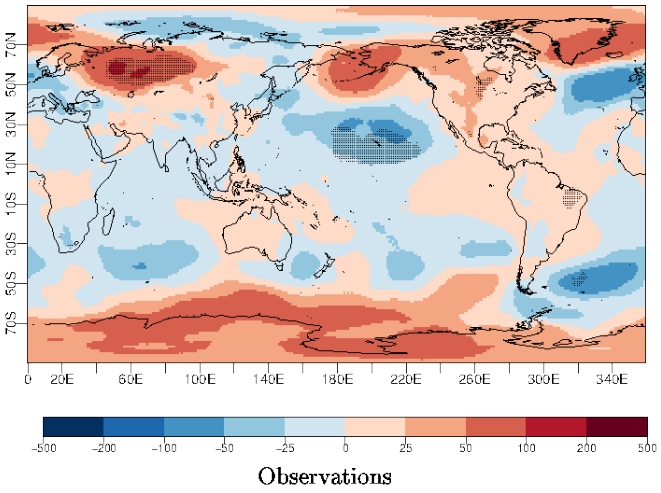


initialisation without volcanoes

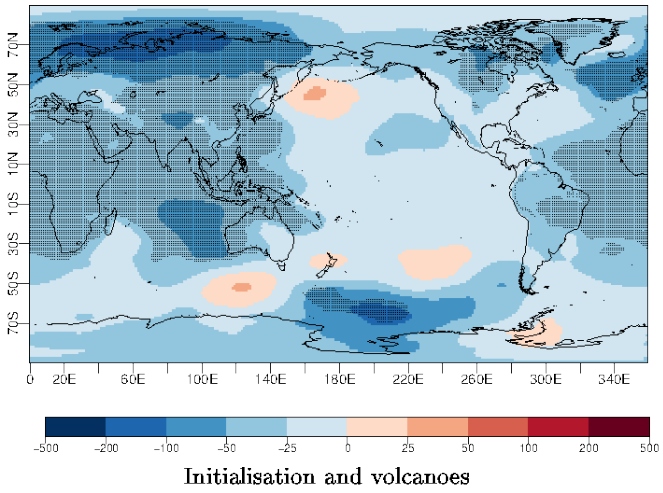
Appendix

→ **Years 3-5 pressure anomalies**

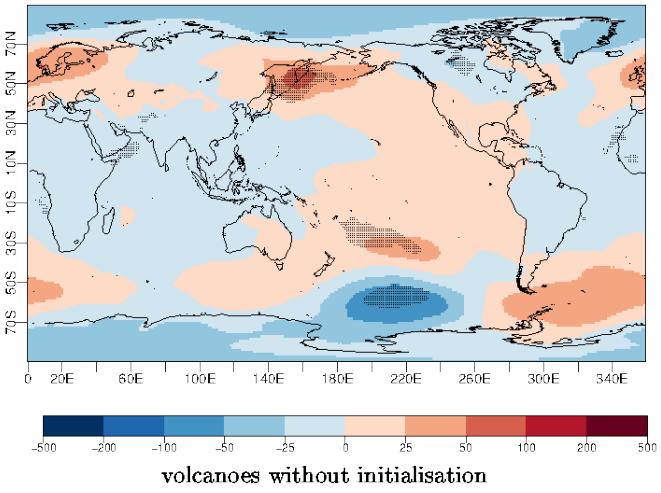
Years 3-5



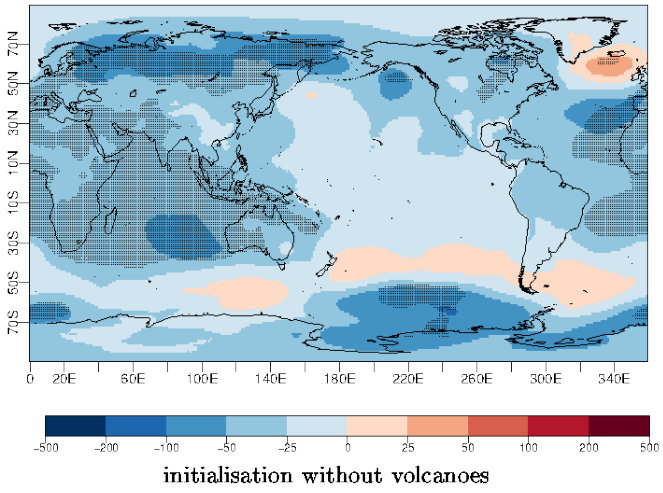
Observations



Initialisation and volcanoes



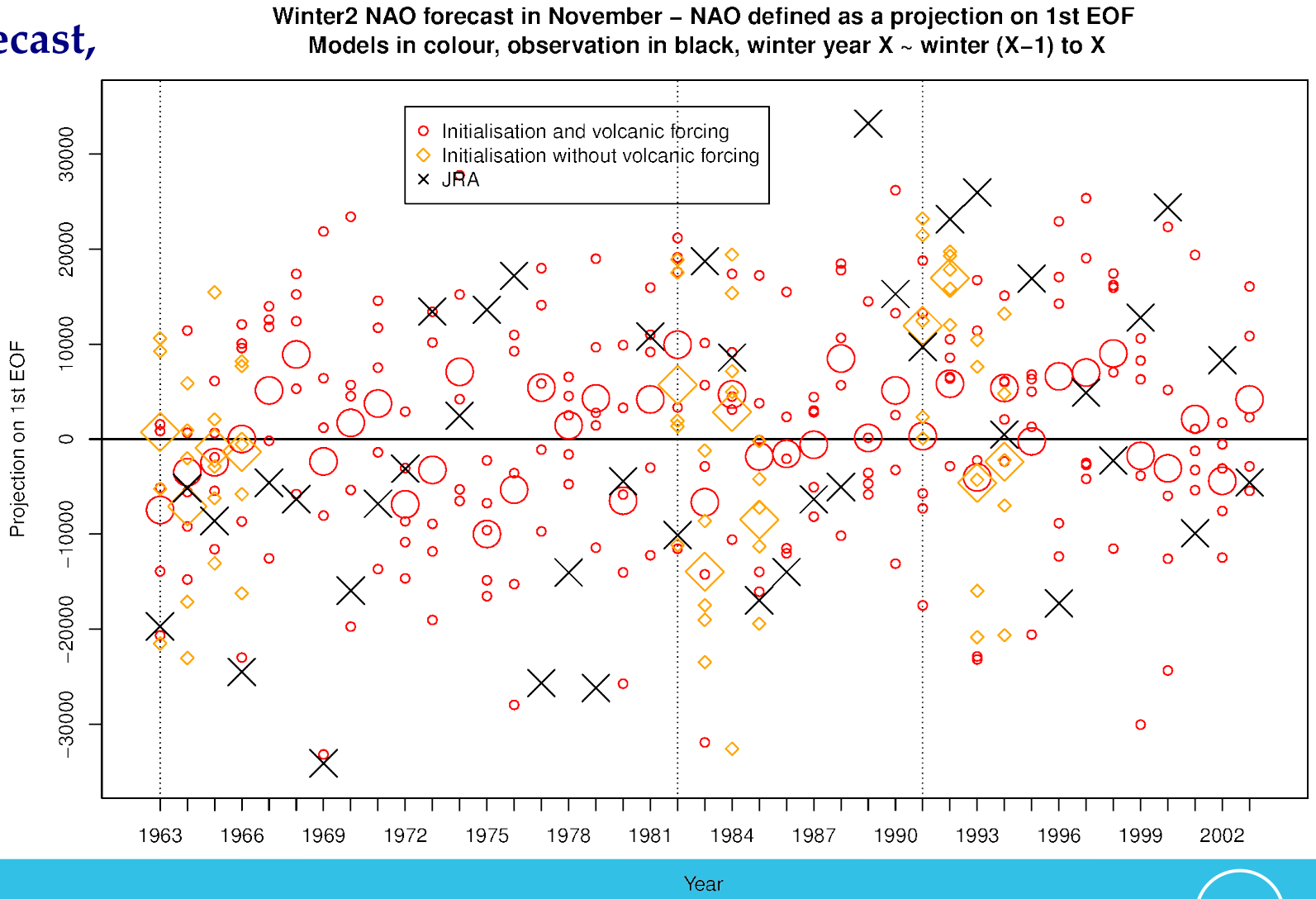
volcanoes without initialisation



initialisation without volcanoes

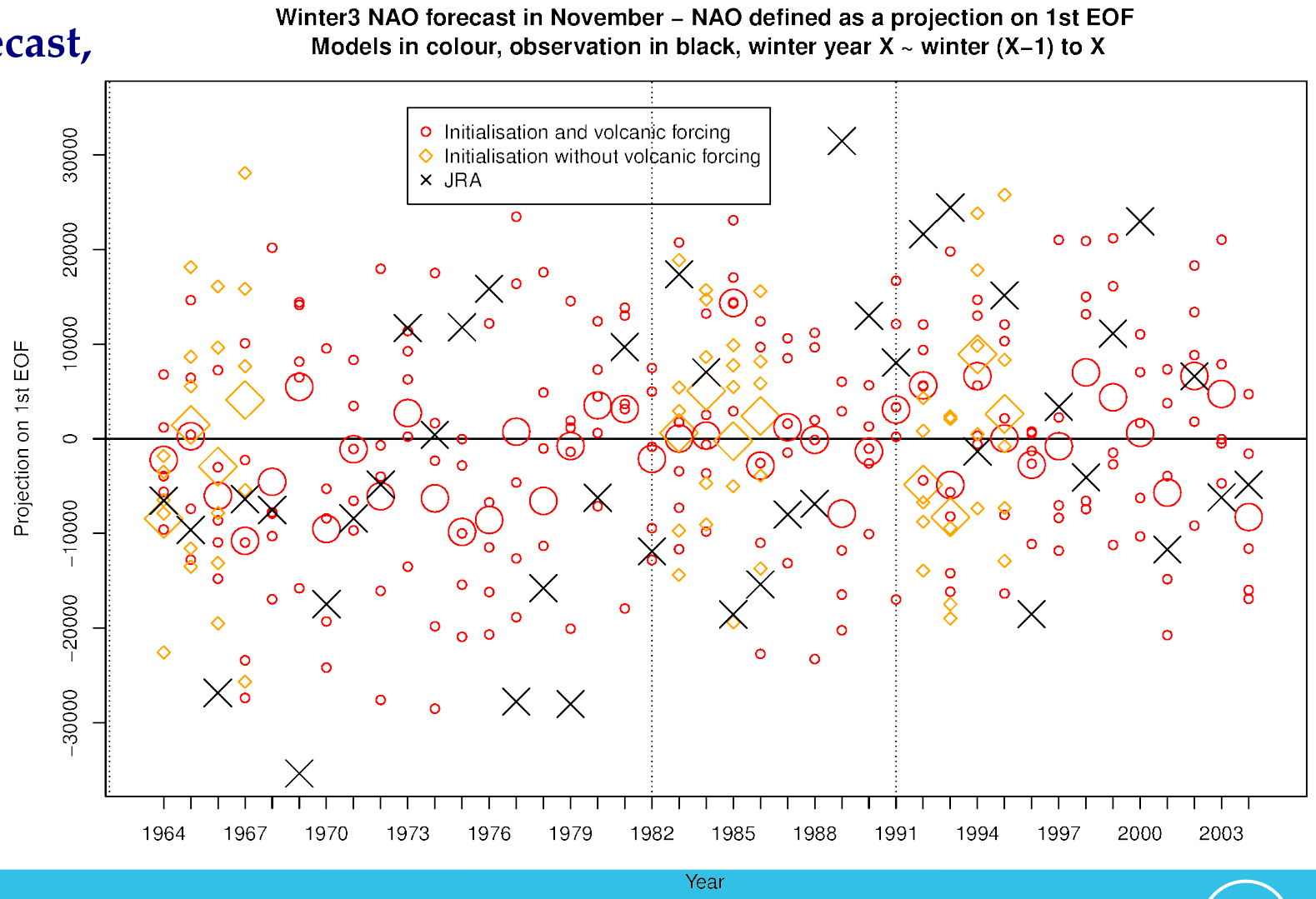
Appendix

→ NAO forecast, winter 2



Appendix

→ NAO forecast, winter 3



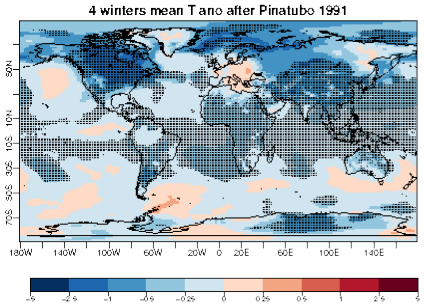
Appendix

→ **Winter temperature anomalies, AMO sensitivities experiments with CNRM-CM5**

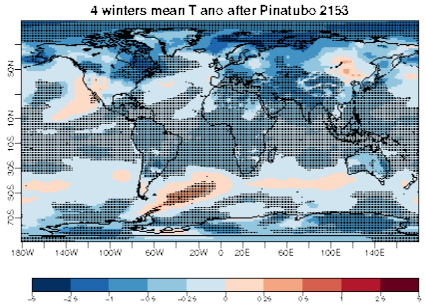
T2M anomalies after Pinatubo

CTL experiments : 13 members; PINATUBO experiments : 13 members
warm AMO corresponds to year 1991 and cold AMO to 2153 in these perfect model experiments
level of significance has been evaluated considering a boostrap of the two sets of experiments (mean difference of 13 members)

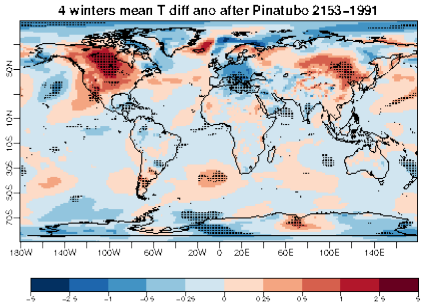
Winter (DJFM) T2M anomalies



warm AMO

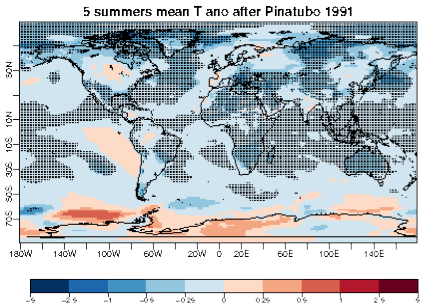


cold AMO

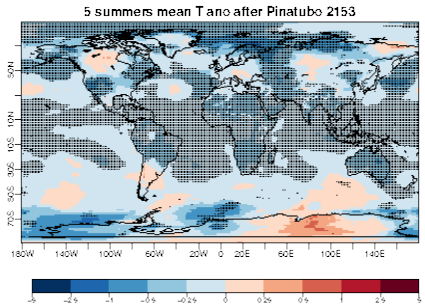


difference (cold - warm)

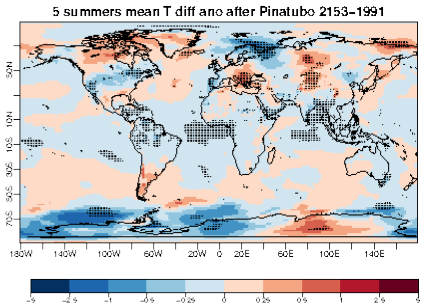
Summer (JJAS) T2M anomalies



warm AMO



cold AMO



difference (cold - warm)

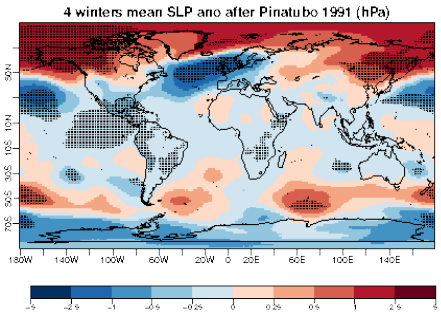
Appendix

→ **Winter SLP anomalies, AMO sensitivities experiments with CNRM-CM5**

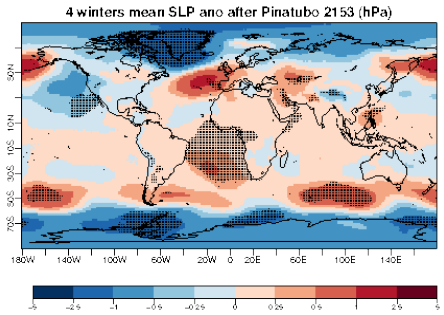
SLP anomalies after Pinatubo

CTL experiments : 13 members; PINATUBO experiments : 13 members
warm AMO corresponds to year 1991 and cold AMO to 2153 in these perfect model experiments
level of significance has been computed from a t-test considering a boostrap resampling (mean difference of 13 members) of the two sets of experiments

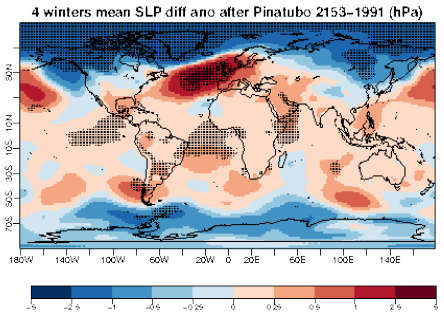
Winter (DJFM) SLP anomalies



warm AMO

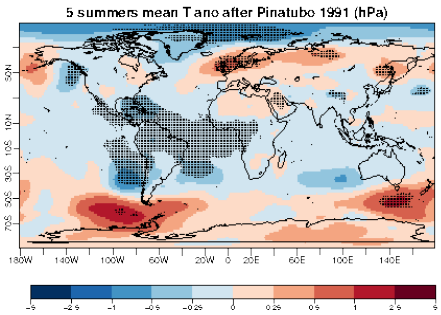


cold AMO

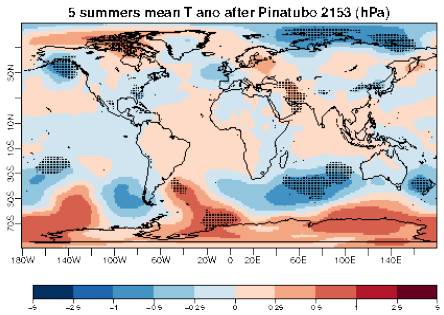


difference (cold - warm)

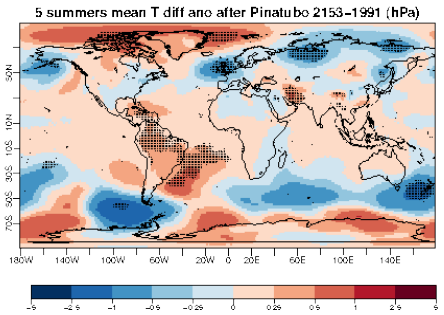
Summer (JJAS) SLP anomalies



warm AMO



cold AMO



difference (cold - warm)

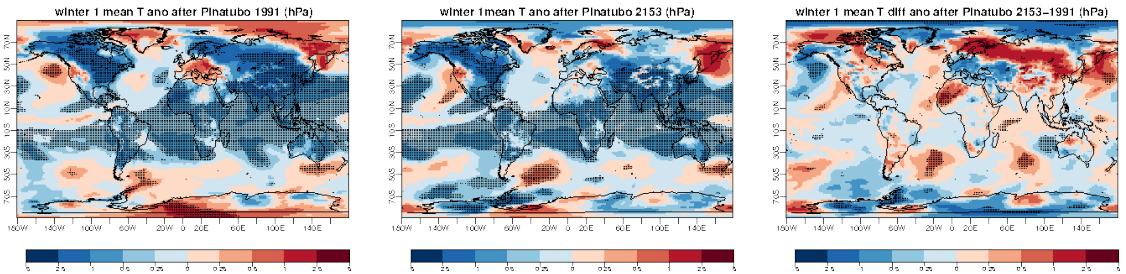
Appendix

→ **Temperature anomalies, AMO sensitivities experiments with CNRM-CM5**

Surface temperature anomalies after Pinatubo

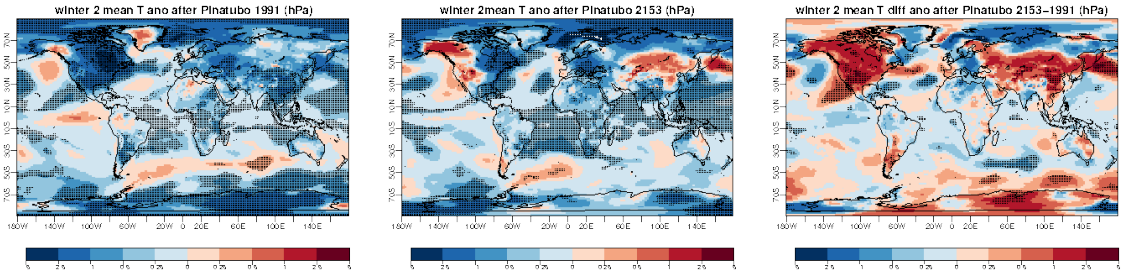
CTL experiments : 13 members; PINATUBO experiments : 13 members
warm AMO corresponds to year 1991 and cold AMO to 2153 in these perfect model experiments
level of significance has been evaluated considering a boostrap of the two sets of experiments (mean difference of 13 members)

First year (DJFM)



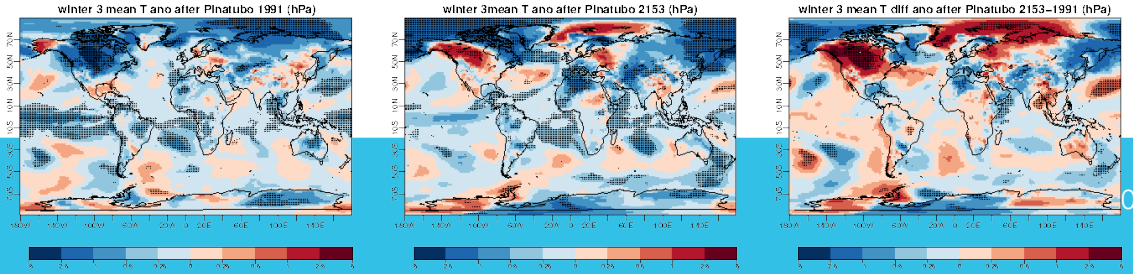
warm AMO | cold AMO | difference (cold - warm)

Second year (DJFM)



warm AMO | cold AMO | difference (cold - warm)

Third year (DJFM)



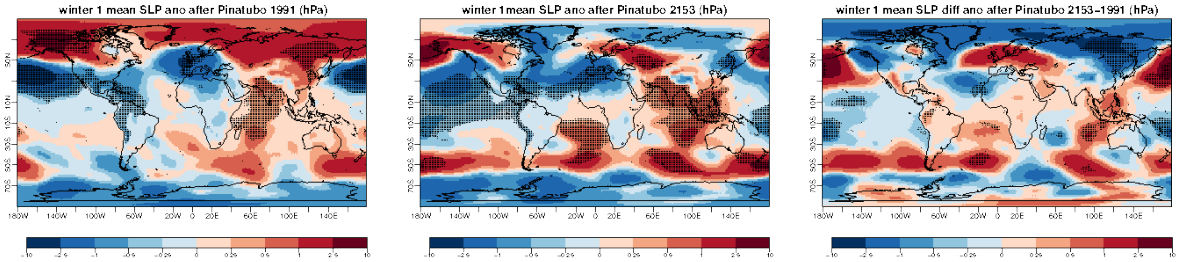
Appendix

→ **Winter SLP anomalies, AMO sensitivities experiments with CNRM-CM5**

SLP anomalies after Pinatubo

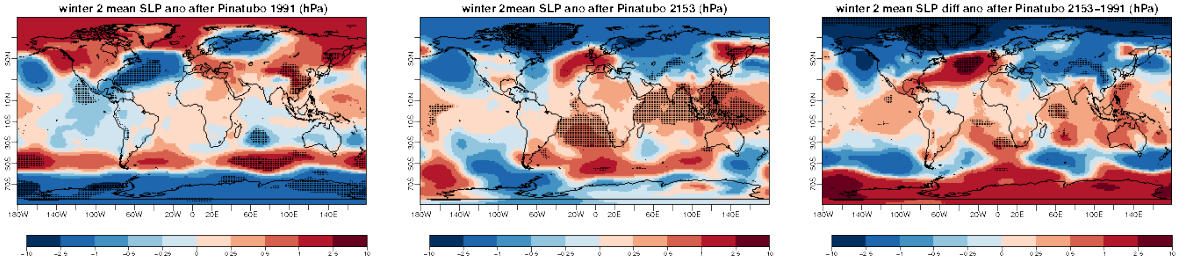
CTL experiments : 13 members ; PINATUBO experiments : 13 members
warm AMO corresponds to year 1991 and cold AMO to 2153 in these perfect model experiments
level of significance has been computed from a t-test considering a boostrap resampling (mean difference of 13 members) of the two sets of experiments

First winter (DJFM) SLP anomalies



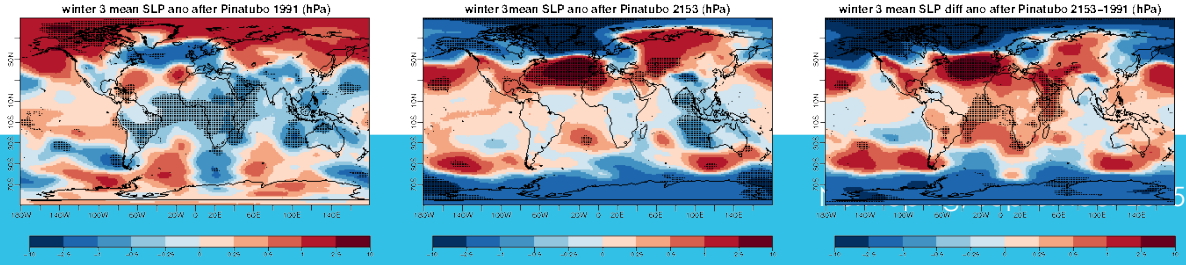
warm AMO | cold AMO | difference cold - warm AMO

Second winter (DJFM) SLP anomalies



warm AMO | cold AMO | difference cold - warm AMO

Third winter (DJFM) SLP anomalies



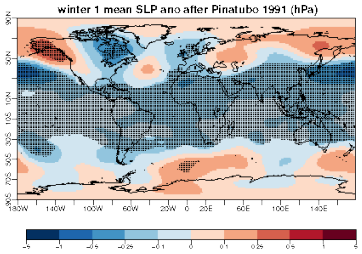
Appendix

→ **Winter Z500 anomalies, AMO sensitivities experiments with CNRM-CM5**

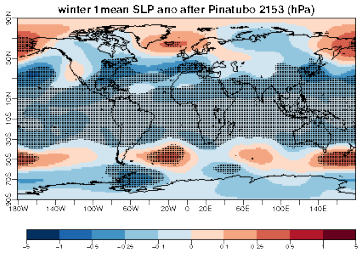
Z500 anomalies after Pinatubo

CTL experiments : 13 members ; PINATUBO experiments : 13 members
warm AMO as observed in 1991 and cold AMO to 2153 in these perfect model experiments
level of significance has been computed from a t-test considering a boostrap resampling (mean difference of 13 members) of the two sets of experiments

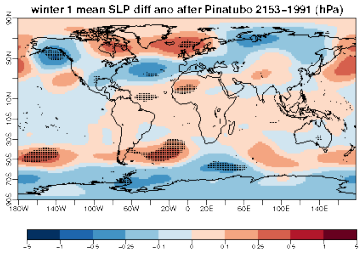
First winter (DJFM) Z500 anomalies



warm AMO

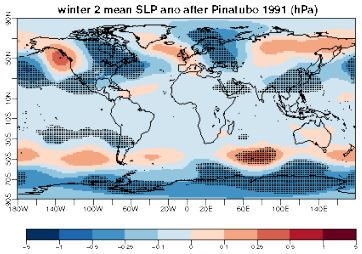


cold AMO

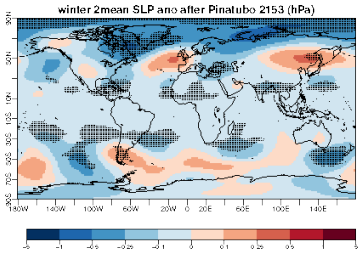


difference cold - warm AMO

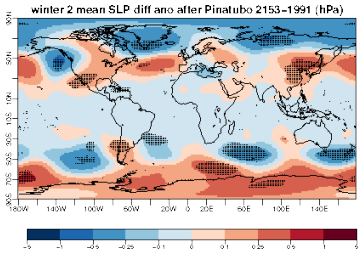
Second winter (DJFM) Z500 anomalies



warm AMO

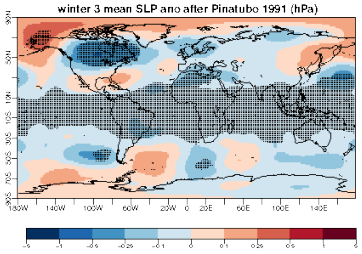


cold AMO

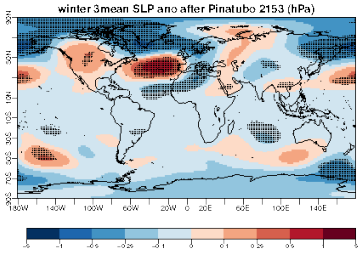


difference cold - warm AMO

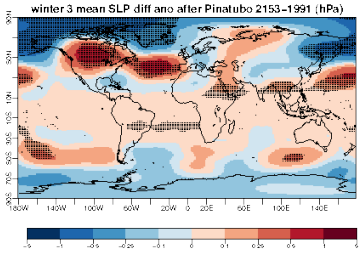
Third winter (DJFM) Z500 anomalies



warm AMO



cold AMO

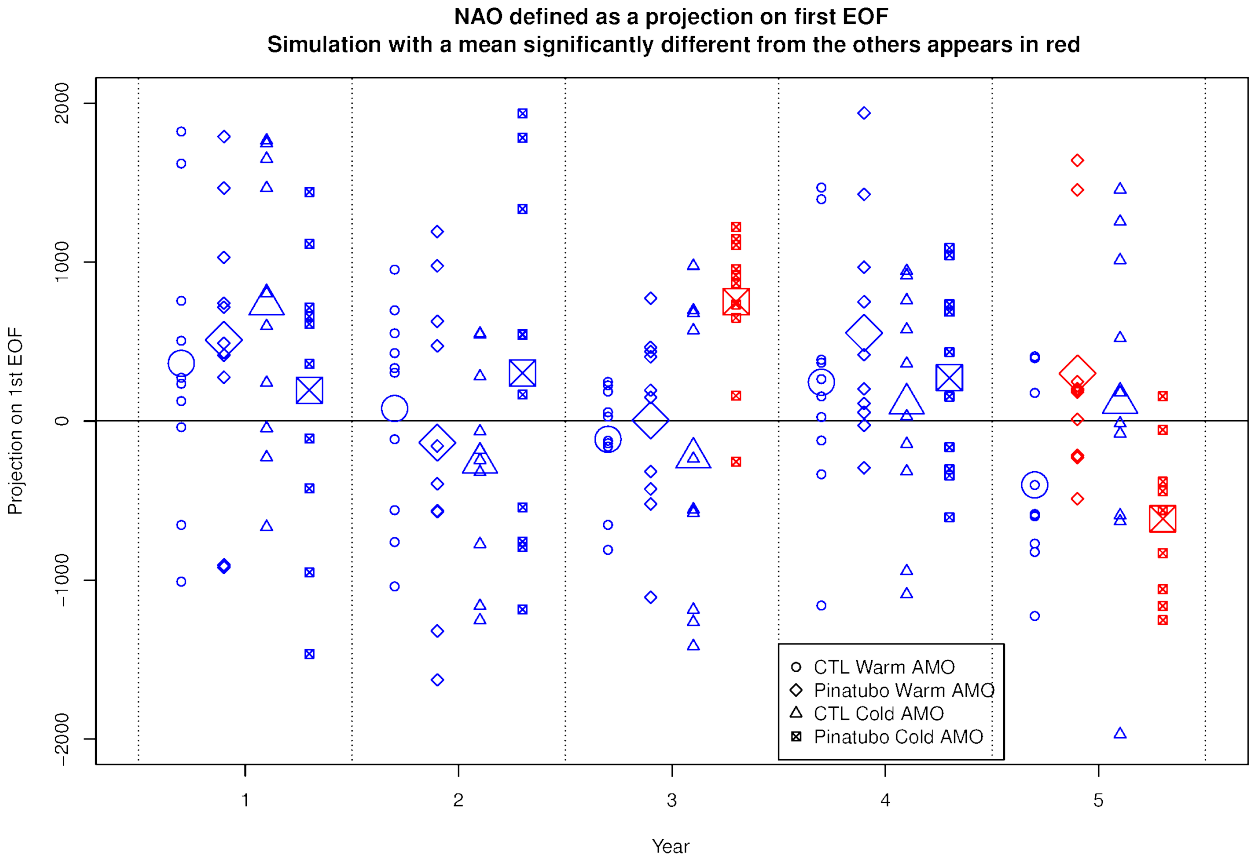


difference cold - warm AMO

Fourth winter (DJFM) Z500 anomalies

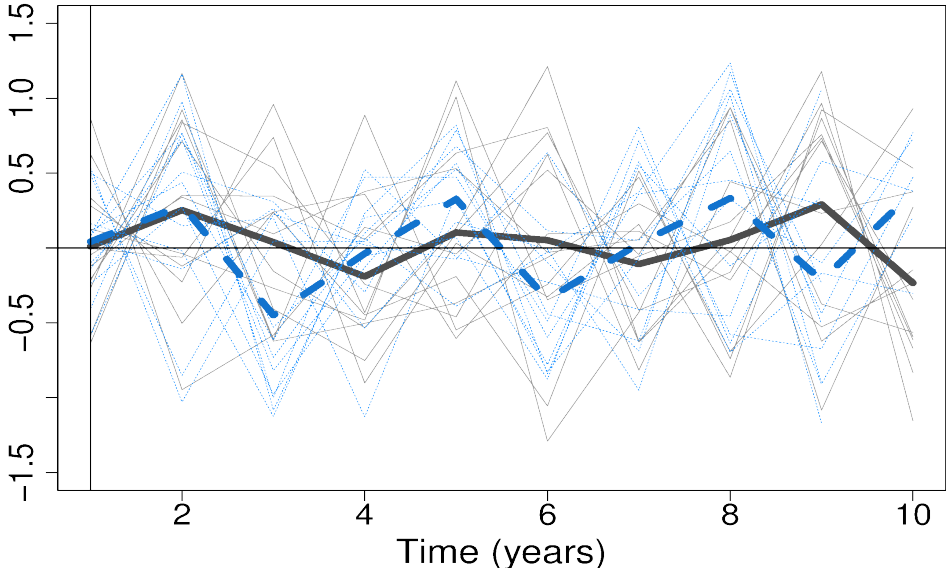
Appendix

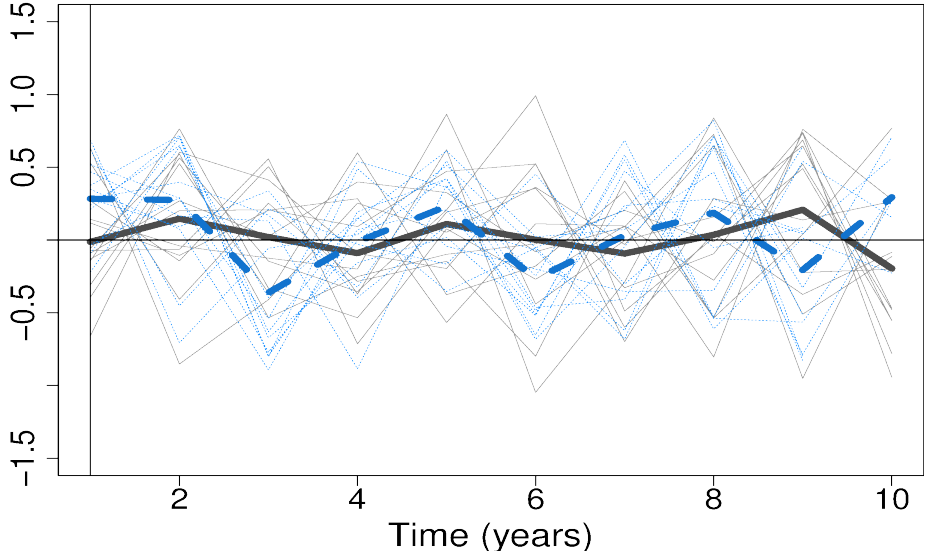
→ The NAO+ signal the third winter following the eruption is also significant in terms of Z500. There is also a significant signal the fifth year



Volcanoes and ENSO

→ **Two ways to define the ENSO index:**

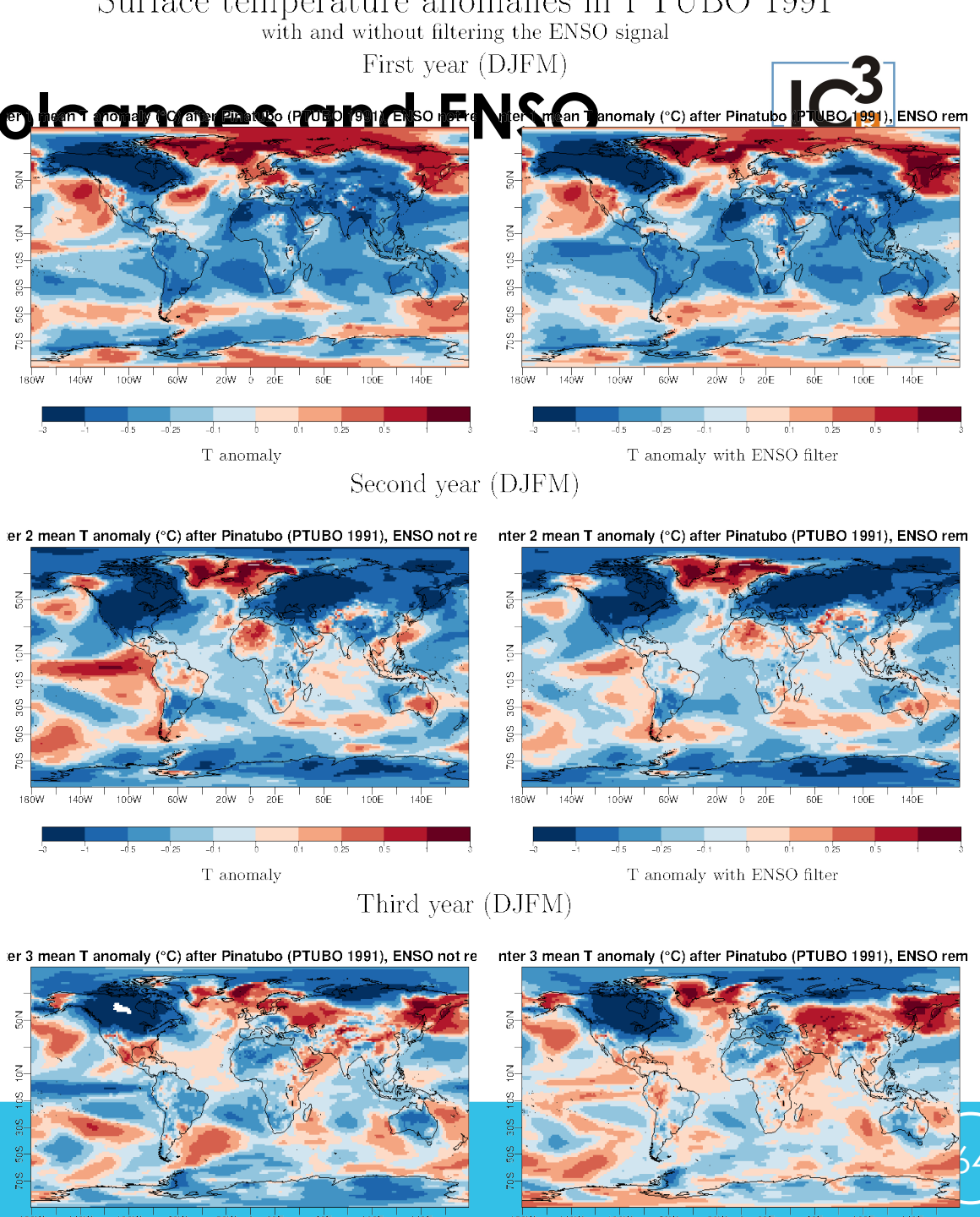




Winter ENSO defined as: (left) the 2m temperature anomaly in the nino 3.4 region (150°E-120°W, -5°S-5°S); (right) the 2m temperature difference between the nino 3.4 region and the tropics (20°S-20°N). Simulations including (blue) and excluding (black) a Pinatubo eruption the year 0, all initialised from climate conditions typical from a warm phase of the AMO.

Volcanoes and ENSO

→ **Filtering the ENSO:**



Volcanoes and ENSO

→ **SLP anomalies with the ENSO filter:**

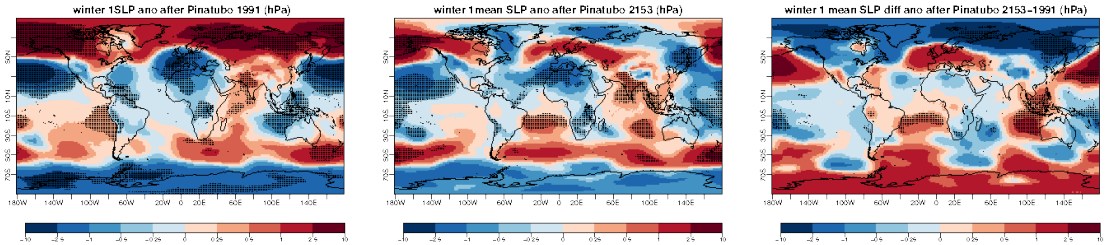
SLP anomalies after Pinatubo

CTL experiments : 13 members ; PINATUBO experiments : 13 members

warm AMO corresponds to year 1991 and cold AMO to 2153 in these perfect model experiments

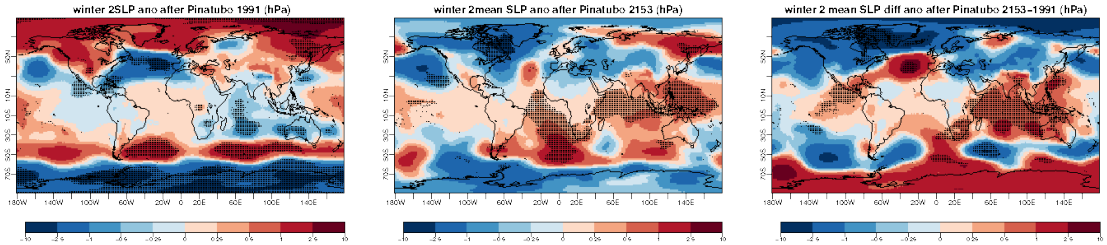
level of significance has been computed from a test consisting in bootstrap resampling (mean difference of 13 members) of the two sets of experiments

First winter (DJFM) SLP anomalies



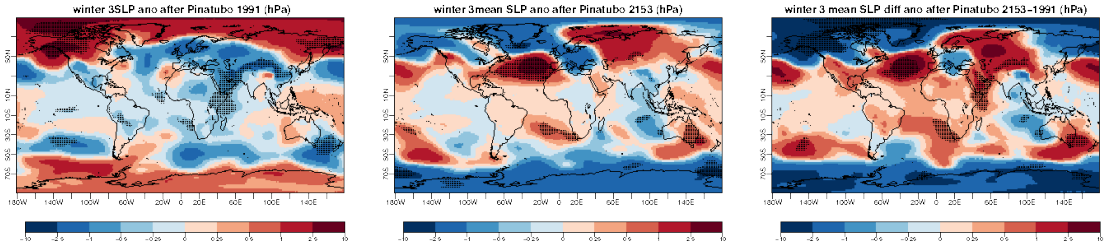
warm AMO | cold AMO | difference cold - warm AMO

Second winter (DJFM) SLP anomalies



warm AMO | cold AMO | difference cold - warm AMO

Third winter (DJFM) SLP anomalies



warm AMO | cold AMO | difference cold - warm AMO

Fourth winter (DJFM) SLP anomalies